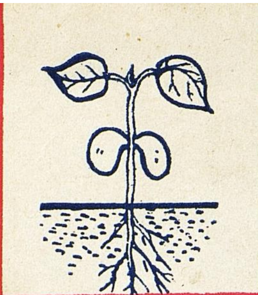
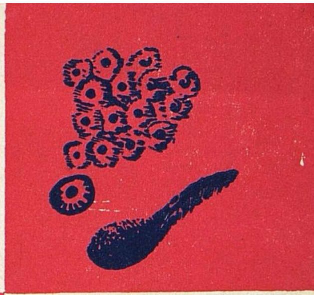
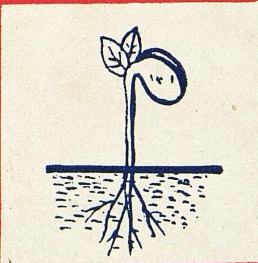


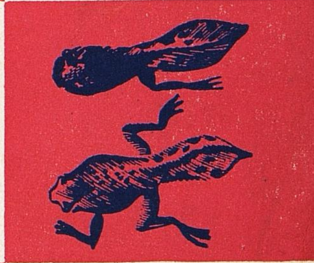


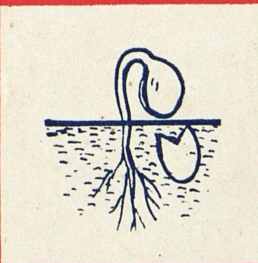
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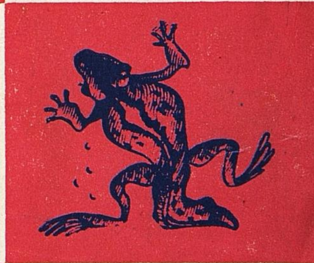
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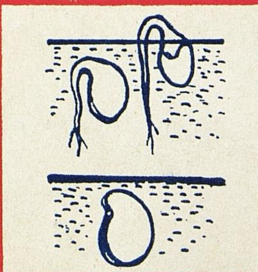
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CONTENTS

Chapter I

INTRODUCTION

Botany is the science of plants.

Significance of plants in relation to agriculture

The cultivation of crop plants started on one day when ancient man collected and stored the seeds of certain plants only for sowing in the next season. Since then he has been discovering a variety of food crops namely cereals, mullets, tubers, fruits, nuts and seeds. As the list of crop plants increased to an astonishing degree he has also learnt different methods of cultivation. He has improved the soil by applying different types of mannure. He has also improved and selected better seeds for cultivation in the next season. He has also learnt the particular season in which he has to sow and harvest his crops. He has also learnt to develop better and improved agricultural implements. With all these, man has become a good agriculturist. His work has been further taken up by the scientists. Several research workers are engaged in plant breeding methods, to find out disease resistant, drought-resistant and high yielding varieties which can be successfully grown. They try to evolve varieties which can give better and quicker yield. The diseases found in plants are fought with many chemicals. Weeds are controlled, so that the crops can grow well and give better yield.

Significance of plants in relation to horticulture

Man was not satisfied with growing food plants only. He started growing a few plants for the beauty of their flowers. He began to develop small gardens around his dwellings to appreciate the beauty of nature. He has collected the plants with beautiful flowers from far and near and has cultivated them. In course of time he has improved the varieties also. Thus he has learnt the different methods of propagating plants like grafting so as to get improved varieties as part of the science of horticulture.

Significance of plants in relation to forestry

Man has come to this earth surrounded by forests. All the useful plants were once found only in forests. Forests are the real source of wealth to human beings. Forests bring rain to the country, thereby providing water to the human beings, animals and plants. Rain water brings fresh blossom on the earth by filling the rivers, tanks, and lakes. It creates many waterfalls from which electricity is tapped. The trees found in forests provide valuable timber which has a definite place in the history of civilisation. Besides timber, cork, rubber, resins, lac, dyes and many other useful products are obtained from the forest trees.

Significance of plants in relation to industry

Plants provide basic raw materials for the industries. Unless cotton is cultivated there will not be many textile industries found in India. There are also several natural fibres such as hemp (*Cannabis sativa*) and flax (***Linium usitalissimum***). Jute extracted from *Corchorus capsularis* and *Corchorus olitorius* forms the important raw material for the jute industry.

Forest trees provide the basis for wood-based industries like sawing, sizing of wood and preparation of wood pulp which is very essential for the manufacture of rayon and paper. Industrial preparation of plywood, is largely dependent upon the supply of wood.

Industrial preparation of paints, oils, varnishes and turpentine are mainly dependent upon the oils, resins and gums, extracted from the plants.

Oil extracted from many oil yielding plants feed the perfumery, cosmetic and soap manufacturing industries.

When there are many industries, they provide employment opportunities for thousands of people. The standard of living of the workers is improved considerably.

Industries also provide the surplus of materials which are exported to foreign countries thereby earning valuable foreign exchange. Plant products obtained from coffee, tea, cashewnut, pepper and cardamom are exported to foreign countries,

Significance of plants in relation to medicine

Plants also give us medicines to keep the body fit and free from diseases. All the systems of medicines such as Ayurvedic, Siddha and Yunani are solely dependent upon the plants for their medicines. Allopathic system of medicines has now turned towards plants like *Rauwolfia serpentina*, *Vinca rosea* etc., so as to get valuable drugs not available from any other source. In addition to the higher plants, the lower group of plants like fungi and actinomycetes also provide us with valuable medicines like Penicillin, Streptomycin, Aureomycin, etc.

Botany in relation to human welfare

(1) *Food:* Plants provide the necessary food materials to the human beings and animals. Without food man cannot live. Green plants possess the wonderful substance namely the chloroplasts by which they can prepare their own food out of the simple raw materials such as carbon dioxide, water and sunlight. Plants store their reserve food materials in their storage organs which are exploited by man. All the cereals, pulses, fruits, seeds and vegetables are obtained only from plants.

2. *Clothes:* Clothes are chiefly made from cotton, flax, hemp and jute which are woven into a variety of colourful fabrics. In addition to this, there are other types of fibres which are made use of in the preparation of ropes, nets, brushes, carpets, etc.

3. *Houses:* Man requires a comfortable place to live in. Whether it is a rich person living in a palace or a poor person living in a hut every one requires the help of plant products for building houses. Doors, windows, furniture and others like boxes are all made from the wood obtained from plants.

4. *Medicines:* The plants not only fulfil the basic requirements of life by providing food, shelter and clothing but also provide the necessary medicines to man. While the indigenous systems of medicine like Ayurvedic and Siddha systems solely depend upon plants for their medicines, Allopathic medicines are also largely prepared from plants like Belladona from *Atropa belladona*, Reserpine from *Rauwolfia serpentina*, Quinine from *Cinchona officinalis* and Digitalin from *Digitalis purpurea*.

5. *Fats and oils:* These are hydrocarbons which remain in solid form at ordinary temperature. These are stored up in seeds and fruits like *Arachis hypogea.* (groundnut oil), *Sesamum indicum* (sesame), *Ricinus communis.* (Castor), *Cocos nucifera* (coconut) and *Elaeis guineensis* (oil palm). The higher energy content of fats favour them for human consumption. In addition to this, these oils are largely used in the manufacture of soaps, candles, plastics, linoleum, etc.

6. *Essential oils:* These are the aromatic volatile oils formed in special cells or glands of plants. Man uses these oils in the preparation of cosmetics, perfumes, creams and powders. eg , Attar from *Rosa damascena,* Geranium oil from *Pelargonium fragrans,* Sandal wood oil from *Santalum album,* lemon grass oil from *Cymbopogon citratus.*

7. *Spices:* Man is not satisfied with the cereals and pulses alone for his food. He wants certain spices which give special tastes and flavour to the dishes. Such spices are obtained from plants like *Cinnamomum zeylanicum* (cinnamon) *Elettaria cardamomum* (cardamom) *Piper nigrum* (Black pepper) and *Eugenia caryophyllata.* (cloves).

8. *Beverages:* In addition to all these man wants a few palatable and refreshing drinks like Coffee, Tea and Cocoa which are obtained respectively from *Coffea arabica, Thea chinensis* and *Theobroma cocoa.* These are known as non-alcoholic beverages which are used by 80% of the world's population.

9. *Rubber:* Natural rubber is prepared from the latex of various erect or climbing woody plants from which many industrial and commercial products are made.

10. *Narcotics:* Human beings have smoked or chewed various plant products for pleasure or even for narcotic effect. Tobacco chewing and smoking have threatened people's health all over the world.

Plants bring fresh showers remove atmospheric pollution, and they also provide food, shelter clothing, medicines, beverages cosmetics, perfumes and many more things to human beings. But do the plants expect anything from us in return? No, definitely

not But as human beings we have a moral responsibility to grow and nourish them with all care and affection. The beauty and glory of Nature has been weaved into volumes of poetry by both the ancient and modern poets in all the languages. Plants provide us with pleasure and peace of mind amidst our multifarious activities, tensions and anxieties.

Botany and its prospects

But is this all in Botany? It is a developing science of plants which investigates their external and internal structures (Morphology and Anatomy), their function with regard to nutrition, growth, movements and reproduction (physiology), their adaptations to the varying conditions of environment (Ecology), their life-history, relationship and classification (Taxonomy), the laws involved in their evolution from simpler groups to more complex ones (Evolution), the laws of heredity governing them (Genetics), their economic uses (Economic Botany) and lastly the methods of improvement of crop plants (Plant breeding) for better use by mankind.

Due to the population explosion many pessimistic futurologists are painting a sorrowful picture about the food problem of human beings in 2000 A.D But men and especially scientists are ingenious enough to find out ways and methods to find food, increase food production on land, water and even in space. By knowing the correct mechanism of photosynthesis the efficiency of food production of plants can be increased many times. Even an unicellular alga like *Chlorella* can be used as food material if scarcity drives human beings to that extent Improvement of crops can be done to produce high yielding, disease resistant varieties. Due to the single cell culture methods, instead of crossing the two different plants, two cells belonging to them can be crossed and a new variety can be produced from it by culture method. Plant breeding methods can be perfected and improved in such a manner that man can cultivate the desired plants with desired characters in the chosen season so that he can be benefited fully.

The threatening menace of pollution of water and air need not worry the intelligent human beings, for he can solve it by growing more and more plants around him.

In addition to the higher plant groups there is much work to be done in the exploitation of food, medicines and the like from the lower groups of plants including the algae and the fungi. Man can lead a happy peaceful life on earth only if he takes care to grow more and more plants on this earth.

Chapter II

ROOT SYSTEM

PARTS OF A PLANT

When a herbaceous small plant is carefully removed from the soil, two important parts are observed. The green portion of the plant above the soil is called the *shoot system.* The portion of the plant below the level of the soil is called the *root system* The shoot system and the root system are continuous

Root system

The root system of the plant is brownish in colour In dicotyledons in continuation of the shoot, there is a large root which grows straight into the soil, called the *main root* or primary root. It may be sparingly or profusely branched according to the need of the plant. The primary root with its branches constitute, the *tap root system.*

Shoot system

This is the portion of the plant found above the soil It consists of the main stem with branches, nodes, internodes, leaves, leaf axils, buds, flowers, fruits and seeds. The portion of the stem with one or more leaves attached is called a *node.* There are several such nodes in a stem. The distance between the two adjacent nodes is known as the *internode* The upper angle formed between the stem and leaf is called the *axil* of the leaf If there is a bud in the axil it is known as *axillary bud.* If the bud is found on the apex of the plant then it is called the *terminal bud.*

The root system and the shoot system without flowers and fruits together constitute the *vegetative body* of the plant because they do not normally take part in reproduction. They are responsible for the manufacture and transport of food materials.

When the plant grows and reaches a certain stage it produces flowers, fruits and seeds. The seeds germinate to give rise to new plants and serve the function of reproduction of the plant. Since

the flowers, fruits and seeds are involved in reproduction, they are included under *reproductive system.* (Fig. 2.1)

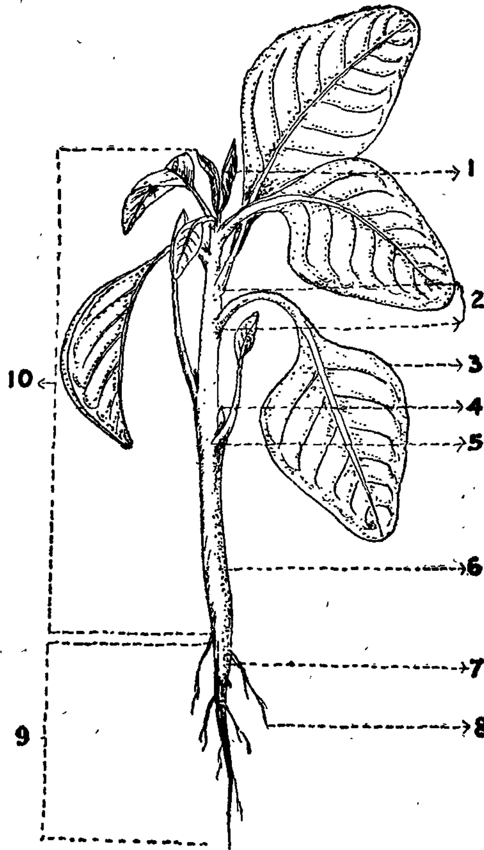


Fig. 2.1 Parts of the Plant
1. Terminal bud 2. Internode 3. Leaf 4. Axillary bud
5. Node 6. Stem 7. Primary root 8. Lateral root
9. Root system 10. Shoot system

ROOT SYSTEM (MORPHOLOGY)

General characteristic features of root

1. The main root grows towards the centre of the earth and therefore is said to be ***positively geotropic.***

The secondary roots grow laterally, and tertiary roots grow in any direction under the soil.

2. The lateral roots arise *endogenously.*

3. There are no nodes and internodes

4 Leaves and buds are absent in the roots.

5. Root hairs and root caps are present in the roots. In water plants like *Pistia,* the root cap is replaced by the root pocket.

Kinds of root systems

1. *Tap root system:* During the germination of the seed the radicle continues to grow and develops into the *primary root* which gives off secondary and tertiary roots in turn, while the primary or tap root grows vertically downwards into the soil the secondary roots grow obliquely at an angle to the primary root. This type of root system is called *normal root system* or *tap root system,* which is characteristic of Dicotyledonous plants like, Bean, Castor, etc (Fig. 2.2)

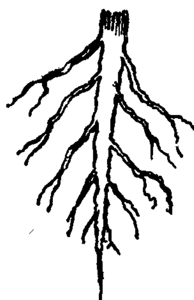


Fig. 2.2
Tap root system

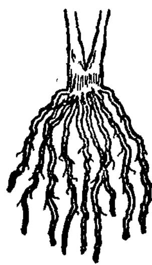


Fig. 2.3
Fibrous root system

2. *Fibrous root system:* During the germination of the seed, the radicle develops into the primary root which is short lived. Instead of this, several roots arise from the stem axis of the embryo These may branch, so as to appear like fibres. So this type of root system is described as the *fibrous root system.* This is characteristic of *Monocotyledonous plants* like paddy, grasses, etc. (Fig. 2.3)

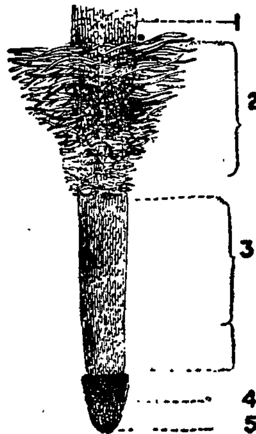
Normal and adventitious root systems

The tap root system with its primary root and several lateral roots is called the normal root system.

When the primary root is short lived, and when the roots arise from some other parts of the plant such as stem or leaf they are called as *adventitious root system.*. Fibrous root system of monocotyledonous plants is a type under adventitious root system. Adventitious root system is also seen in a few dicotyledonous plants.

Regions of the root

In both normal and adventitious root systems four distinct *regions* or *zones* may be observed. The regions of a root are best



Fig, 2.4 Regions of the root

1. Region of cell maturation 2. Root hair region 3. Region of cell elongation 4 Region of cell division 5. Root cap

studied from some germinating seed like mustard or pea: (1) Root cap region (2) Region of growth (cell division and cell enlongation) (3) Root hair region (4) Region of maturation (Fig. 2.4)

Functions of the root

1. *Fixation or anchorage:* Plants are fixed to the soil by their deep seated and extensively branched root systems. Even tall trees like *Eucalyptus* and *Teak* are able to withstand the high velocity of the wind by their root system.

2. *Absorption:* The root system is surrounded by soil particles with thin films of water and mineral salts. The roots absorb this water and mineral salts and make use of them in the preparation of their food.

3. *Conduction:* Roots also conduct the water and mineral salts absorbed by the root hairs to the other parts of the plant.

MODIFICATIONS OF ROOTS

Besides the above mentioned normal functions, roots may be modified in order to carry on special functions. In all these cases the form of the root is also changed and the root is said to have undergone modifications. Either tap roots or adventitious roots may undergo such modifications.

1. TUBEROUS ROOTS

In some plants, the roots serve as storehouses of food materials. Therefore they have a swollen and fleshy appearance. Such roots are called *tuberous roots* or *Root tubers* Very often portion of the plant found above the soil (aerial parts)die out during unfavourable season. When the season becomes favourable, new plants develop from the underground fleshy root Thus they serve for perennation.

A. Tap root modifications

Some plants store their food materials in their tap roots, and become swollen. Such swollen tap roots are named according to the shape assumed.

(*a*) *Conical:* When the root is broad at the top and gradually tapers downwards like a cone, it is said to be conical *e.g.*, carrot (*Dacus carota.*) (Fig. 2.5)

(*b*) *Fusiform:* When the root is broad in the middle and tapering towards both ends like a spindle, it is said to be fusiform *e.g.*, Radish (*Raphanus sativus.*) (Fig. 2.6)

(*c*) *Napiform:* When the root is considerably swollen at the upper part and abruptly tapering towards the lower end, it is called napiform, *e.g.*, Beet root : Turnip. (Fig 2 7)



Fig. 2.5
Conical

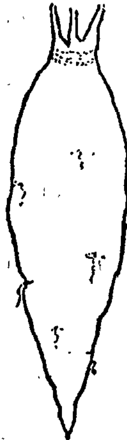


Fig. 2.6
Fusiform

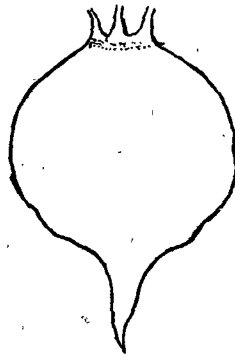


Fig. 2.7
Napiform

B. Adventitious root modifications

(*a*) In sweet-potato adventitious roots become swollen and form the edible root tubers. It is not having a definite shape of its own. (Fig. 2.8)

(*b*) *Fasciculated Roots:* When a number of adventitious root tubers are found in a cluster at the base of the stem they are said to be fasciculated as in *Dahlia*, *Ruellia tuberosa* and *Asparagus racemous*. (Fig. 2.9)



Fig. 2.8
Adventitious root tuber

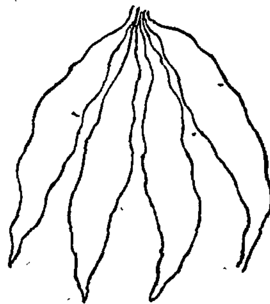


Fig. 2.9
Fasciculated roots

(c) *Nodulose:* When the tips of the roots are swollen they are described as nodulose *e.g.*, Mango ginger, *Cyperus rotundus.* (Fig. 2.10)

(d) *Palmated:* When the roots are divided at their tips, they will appear like a palm and so described as palmated. *e.g*, *Habenaria* (Fig. 2.11)

(e) *Moniliform:* Some roots are alternately swollen and constricted presenting a beaded appearance and this is described as moniliform *e.g.*, *Dioscorea alata.* (Fig. 2.12)

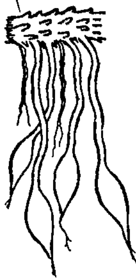


Fig. 2.10
Nodulose roots

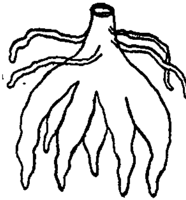


Fig. 2.11
Palmated roots

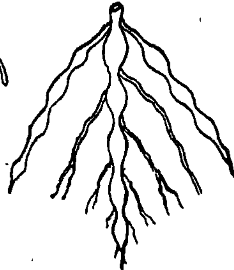


Fig. 2.12
Moniliform roots

2. PROP ROOTS

Banyan tree is a large tree with a number of horizontally growing branches from which aerial adventitious roots grow

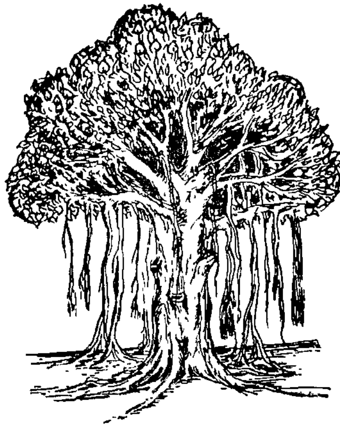


Fig. 2.13 Prop roots

downward into the soil They increase in thickness and are like pillars, giving additional support to the plant. Long living banyan trees cover large areas by their spreading branches supported on a number of prop roots. Such a large banyan tree is found in the Theosophical Society Compound, Adyar, Madras. e.g., Banyan tree (*Ficus bengalensis*). (Fig. 2.13)

3. CLIMBING ROOTS

Some plants cannot grow erect and climb upon other large plants for their support. Such plants are called ***weak stemmed climbers***. They develop adventitious roots at their nodes and help to fix the plant to the support. Since these roots are helpful in the act of climbing they are called climbing roots. *e.g.*, Betel vine (*Piper betel*) Pepper (Fig 2.14)

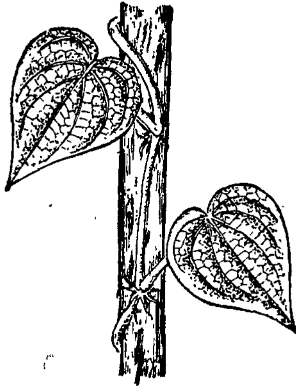


Fig. 2 14 Climbing roots

4 RESPIRATORY ROOTS

Some plants grow in salt marshes Their roots suffer from lack of oxygen. Some of the lateral roots grow above the surface of the water or soil. Such roots contain numerous air spaces inside and have many small openings at their surfaces. Exchange of gases can take place through these roots. Since they are useful

in respiration they are said to be ***respiratory roots e.g., Avicennia, Rhizophora.*** (Fig. 2.15)

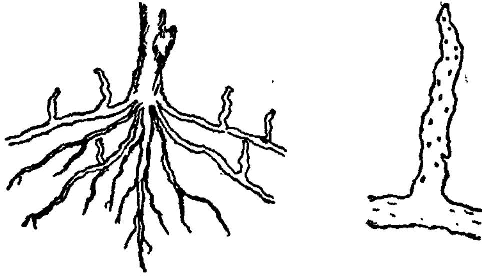


Fig. 2.15 Respiratory roots

TISSUES (ANATOMY)

The microscopic examination of the plant body of any higher **plants reveals** that it is made up of countless number of and a variety of cells. A group of cells having a common origin, development, position, structure and function becomes a particular tissue. The different kinds of tissue are all arranged (at the same time) in a particular pattern and in varying combination and proportion in any given organ and also with respect to each other. Variations observed in these respects often reflect the characteristic features of a species. In such an organization the arrangement of tissues, a combination of both living and non-living (dead) tissues can be seen (Fig. 2.30,2.34) forming a republic and both discharge in unison their respective roles towards the welfare of the plants. Before we study the internal structures of the important plant organs and the tissues present in them in detail, let us have a preliminary understanding of the general characteristics of different important kinds of tissue. The tissues depending upon their homogeneous or heterogeneous composition are classified for the sake of convenience into simple and complex tissues. **The** simple tissue the one containing only one type of cells, whereas in a complex tissue more than one type of cells is present.

I. Simple Tissues

1. *Parenchyma:* Parenchyma cells are the simplest cell type. The cells are living containing cytoplasm and nuclei. Their cell walls are usually thin and sometimes thick. They appear hexagonal (Fig. 2.17) or rounded in transections (Fig. 2.18) and arranged with or without intercellular spaces. Parenchyma is also the commonest tissue and widely distributed to a greater or lesser extent in every organ and throughout the plant body. In other words, this tissue is predominant in cortex, pith, primary and secondary xylem (wood) and phloem of every organ and the endosperm of seeds. Parenchyma cells in their simplest unspecialized conditions resemble a particular geometrical model having 14 sides (facets) and such a model is called orthic tetrakaidecahedron (Fig. 2 16). But the cells are usually variable in shape and under such situations the number of sides may appear lesser than the typical number. The xylem parenchyma cell is either elongated or subdivided to form a strand (Fig. 2.20). Because of their living condition the cells are capable of undergoing further division, growth and modifications. Parenchyma is credited with a variety of function, depending upon their location within and with respect to the organ as follows: photosynthesis (mesophyll, chlorenchymatous hypodermis of young aerial organs); food storage (underground stems) ; water storage (succulent stems) ; wound healing and the development of adventitious roots and buds. Considering the parenchyma from the above mentioned stand points it appears to possess immense potentialities in terms of growth, development, differentiation (physiological and morphological changes occurring in a cell, tissue or organ usually resulting in a specialized condition) and functions. Therefore the parenchyma cell is said to have totipotentiality

2 *Collenchyma:* This is one type of mechanical tissue present in the peripheral parts of aerial organs namely young stems, petioles and ribs of lamina (Fig. 3.39 ; 3.44) but usually absent in underground organs and older parts . This tissue develops either continuously consisting of few to several layers of cell or in the form of discrete strands. The individual cells of the tissue are more or less elongated characterized by unevenly thickened primary walls (Fig. 2.27). The cells are living containing protoplasts and thus showing a capacity for further growth

and division. The more common form of collenchyma is known as angular collenchyma (Fig. 2.19). This is charecterized by the wall thickenings occurring in vertical strips at the junction of cells (Fig. 2.27). As a result of this kind of thickening the intercellular spaces become either small or totally lacking (Fig. 2·19.) The cell walls show finely lamellated thickenings which are due to the successive alternate deposition of cellulose rich and pectic poor layers. The high percentage of pectic substances (a group of complex carbohydrates) in their walls accounts for their correspondingly high hydrated condition. Collenchyma tissue imparts strength and elasticity to the organs concerned.

3. *Sclerenchyma*: This is another type of mechanical tissue. Under this general term sclerenchyma two categories are recognized based upon their respective size,factor, distribution and mode of origin. In one category of sclerenchyma the individual cells are either isodiametric (with diameters equally long and thus regular in form ; (Fig. 8.7) or polymorphic but in either case they are usually broader than long except a few unusual fibre like elongated types. They develop as a result of further modifications of the existing parenchyma cells or from special initials of their own. The cell walls possess simple or ramiform (branched) pits (Fig. 8.7). They are present in any diffuse manner in any part of the ground tissues, cortex, at vein endings of the leaf, seed coat (testa), pericarp (fruit wall) and barks. This category of sclerenchyma is known as the *sclereids*. The second category of sclerenchyma known as the fibers (also spelt as fibers) are usually and considerably longer than broad (narrow) with tapering ends (Fig. 2.25). The lateral walls possess bordered pits (minute openings arched over by the secondary wall thus forming borders) which may be well developed or much reduced (Fig 2 26) or even absent. The fibres develop from definite meristems (tissues concerned with the formation of new cells by division) The fibres occupy a definite position within an organ such as hypodermis, secondary xylem and phloem and sheaths of vascular bundles However both sclereids and fibres are characterized by exceedingly thick, usually lamellated cell walls which are differentiated into primary and secondary wall layers. The sclereids give hard, incompressible texture to the organs concerned while the fibres give support and hardness.

4 *Epidermis*. The epidermis is the outermost surface layer of every organ of the primary plant body. But in the older parts this layer is replaced by substitute layers of different kind, structure and origin. The cells are arranged in such a way that they form a continuous layer arranged without intercellular spaces (Fig. 3.43). The cells are either uniform in size, arrangement and shape (Fig. 3.44) or more frequently variable (Fig. 3.43). However the epidermis, being the outermost layer directly exposed to the environment, is overlaid with a substance known as cutin which ultimately develops a thick or thin layer known as the cuticle. The mode and process of formation of cutin is called cutinization and that of the cuticle is known as the cuticularization. Cuticle is however wanting in the epidermis of the underground organs and submerged portions of water plants. Because of these structural characteristics, the epidermis is well known for its efficiency as a protective layer. Besides this protective function it also takes part in exchange of gases and water loss (through stomata (photosynthesis, respiration and transpiration). The continuity and homogeneity of the epidermis is usually interrupted by the development of stomata (young herbaceous stems and leaves) and hairs (trichomes). The cell walls are straight or undulate (wavy), thick or thin and the thickness of the walls may be even throughout or uneven. Cells usually possess protoplasts and therefore they possess a variety of substances such as anthocyanin pigments (water soluble pigment responsible for red, blue and purple colours), tannin (group of phenolic derivatives, brown in colour), oils, crystals of different chemical composition, silica, etc. In some shade loving plants chloroplasts are also present. Each stoma (pl. stomata) possesses a pair of highly specialized, structurally modified cells known as guard cells enclosing in between minute microscopic opening which leads internally into a substomatal chamber (Fig. 3.40). The stomata are in turn immediately surrounded by certain number of ordinary epidermal cells/or cells which are totally different from the remainder (Fig. 3.40 ; 3.41). However the cell walls of guard cells are unevenly thickened in such a way as to give rise to outer and/or inner horn like projections known as outer and inner ledges respectively (Fig. 3.40). Guard cells are living containing protoplasts and chloroplasts. They exhibit a mechanism regulating the opening and closing of the stomata and thus they are

able to participate efficiently in certain important physiological processes (transpiration, photosynthesis and respiration).

II. Complex Tissues

5. *Xylem*: This is the principal water and solute conducting tissue having a complex organization in the sense that it contains vessels or tracheids, fibre tracheids or libriform fibres, xylem or axial parenchyma and ray parenchyma. The xylem is classified into primary and secondary based upon the source from which it is derived, age of the organ and the structural characteristics particularly of its tracheary elements. The xylem that is formed by the procambium (primary meristem giving rise to primary vascular tissues) in a young organ consists of two kinds of element namely protoxylem and metaxylem elements. The first formed elements of the primary xylem are known as the protoxylem and the later formed ones are called metaxylem (Fig. 8.9). The protoxylem elements are usually characterized by annular, helical, and spiral thickenings (Fig. 8.9). These thickenings refer to the secondary wall which is internally superimposed upon the primary wall in the above mentioned pattern. On the other hand the elements of the metaxylem possess reticulate thickenings and pitted elements (Fig. 8.9). Likewise the length and the width of protoxylem and metaxylem elements seem to indicate differences between them. The protoxylem elements are usually narrower (Fig. 8.9) and considerably longer than those of the metaxylem although such variations in them are not clear cut but seem to be rather gradual. The various elements of the secondary xylem are produced by the vascular cambium in the older organs. The vessels possess perforations at the end walls (Fig. 2.23) which may be simple or multiple, the former condition is known as simple porous (Fig. 8.8), the presence of which is considered to be one of the important and characteristic qualifications of the vessel. Because of this particular feature the vessels are also known as the perforate elements in contrast to the fibres and tracheids in which they are totally wanting and hence the latter known as the imperforate elements. (Fig. 2.21). The vessels, fibres, and tracheids are characterized by the presence of a continuous layer of secondary wall. The lateral walls are usually provided with minute openings known as the bordered pits (Fig. 2.21 ; 2.22). The bordered pits with res-

pect to the relative abundance, size, shape and pattern of distribution show variations The vessel is a composite structure consisting of more than one similar unit or element arranged one over the other in a vertical manner (Fig 3.16) and the individual unit is known as the vessel member or element (Fig 3 16) However the protoplasts disorganize ,when the elements become fully differentiated and thereby becoming dead.

Tracheids are elongated cell types with narrow lumina, angular in cross section and overlapping with each other by their tapering end walls They possess well developed bordered pits (Fig 2 21 ; 2.22) The tracheids are dead cells when they become fully differentiated. They discharge dual functions namely conduction of water through bordered pits in the absence of terminal perforation and support.

6. *Phloem:* Just as the xylem the phloem also is one of the important components of the vascular tissues in taking part in the conduction of food materials to different parts of the plant. As a complex tissue phloem contains sieve elements (sieve tubes or sieve cells), albuminous or companion cells, phloem parenchyma, phloem fibres and phloem rays. Depending on the source from which the tissue is derived and the age of the organs, this is classified into primary and secondary phloem. The primary phloem is derived from the procambium and present in the organs which are still young. On the other hand the secondary phloem originated from the vascular cambium after the maturation or full development of the organs.

Sieve elements are the principal components of primary and secondary phloem The sieve element is called so because of the presence of minute perforations known as the sieve areas at its lateral and end walls bearing a resemblance to the sieve plate of the household item. The sieve elements develop specialized sieve areas in the form of distinct sieve plates particularly in their end walls bearing few to several sieve areas (unspecialized) on their lateral walls. They are known as the sieve tubes which are usually reported in angiosperms. Vertically arranged series of this kind of cells resembling conduit pipes is called the sieve tubes and the individual component of this series is known as the sieve tube member or element (Fig 3 17 , 3 18) However

it is interesting to know that the sieve elements appear to be remarkable cell types because of their complicated developmental history and the absence of nucleus necessary in a living cell (enucleate) when fully differentiated. Thus a fully developed sieve element is considered to be a living cell type despite the absence of a nucleus is an unique model of its own without a parallel among the cell types known. The walls are relatively thin but usually having unlignified thickening. This thickening is laid in a wavy manner and presents a pearly white lustre and hence it is known as the nacré. The sieve element becomes devoid of all the original cytoplasmic contents except a thin peripheral layer of cytoplasm and slim (proteinaceous substance) traversing the entire cell when fully developed. Each pore in the sieve plate is traversed by cytoplasmic strands thereby establishing connection and communicating with cells lying below and above. The pores are ensheathed by a cylinder of callose (a kind of carbohydrate) as seen in (Fig. 3.19) When the sieve tubes are in a functioning stage the callose exists only as a tubule (Fig. 3.17) but at the non functioning stage the callose develops to such an extent as to block the pores and camouflage even the entire sieve plates (Fig. 3.18).

The companion cells are now considered as specialized parenchyma like cells. They are always associated with sieve tubes but occurring in variable number and position (Fig. 3.18). Developmentally the companion cells are considered to be the sister cells since both these cells and the sieve tubes develop from the same source. But unlike the sieve tubes these are nucleated till their death. The companion cells help the sieve tubes by regulating the translocation. According to the recent findings the companion cells resemble the secretory cells. The functional counterpart of the companion cells in gymnosperms and lower groups of plants is known as the albuminous cells. For phloem parenchyma, fibres and rays, see above.

ANATOMY OF THE ROOT

The roots usually represent the underground organ of the tracheophyta. But there are examples in which the roots develop adventitiously from different organs and positions of the plant namely stem (climbing roots of *Piper nigrum*), branches (prop roots of *Ficus bengalensis*), leaves (epiphyllous roots of *Kalanchoe* sp.)

and roots (pneumatophores of *Avicennia officinalis*) or as in the case of parasites (*Loranthus* sp.) they are present as modified structures known as the haustoria. Roots of certain gymnosperms and Fabaceae (Papilionaceae) become modified due to the invasion and influence of bacteria and fungi thereby causing root nodules and mycorrhizae respectively. Normally in seed plants the radicle of the embryo develops directly into the tap root which in turn gives rise to lateral roots. As a result of this kind of development a distinct profusely ramifying roots system is established in course of time. In certain cases of seed plants particularly among the monocotyledons, although the radicle develops into a primary root it is soon replaced by adventitious fibrous roots which are emanating from the bases of the stems. Although the roots in the majority of cases appear to be part and parcel of the plant body and are present in continuation with the main leader of the shoot system, judged from the standpoint of development, morphology, anatomy and physiology, they appear to be different organs. Roots in general and under normal conditions give anchorage and serve as organs of absorption. But under certain special conditions, in addition, they serve as organs of storage (*Manihot utilissima*-Tapioca), additional support (*Ficus benghlensis*- Banyan tree), climbing (*Piper nigrum*-Pepper), assimilation (*Vanda tessellata* Hook. epiphytic orchid), aeration (*Avicennia officinalis* L.-White mangrove ; Upattha) and symbiosis (*Erythrina indica* Lam.-Coral tree ; Kalyana Murungai). However, the study of anatomy of the root with the help of *Ricinus communis* (castor) may convince how the internal organization, the different types of tissue and tissue system maintain a compromise with respect to the functions discharged by the roots.

Primary Structure

Root cap: The growing and advancing tips of the roots inside the soil are protected usually by a few to several layers of parenchymatous cells. These cells form the root cap or calyptra (Fig. 2.28). The root cap or calyptra is formed by a meristem known as the calyptrogen (Fig. 2.28). The cells are living and contain amyloplasts (colourless plastids forming starch) producing amylum or starch. The root cap is supposed to protect the young delicate growing tips from damage. The cell walls of the root cap cells possess mucilaginous consistency due to the presence

of pectic substances in them. The root cap is also supposed to be the potential site for causing geotropic curvature of the roots. As the root tips advance the outermost layers of cells are successively sloughed off from time to time and new layers originate and are added on from within.

Rhizodermis or *epiblem*: This is a single layer of thin-walled cells arranged in a closely packed manner without intercellular spaces (Fig. 2.29). Sometimes this layer is cutinized or suberized in case it is persistent. The opinion of some anatomists who prefer to distinguish the root epidermis from that of the shoot is to designate the former by separate terms rhizodermis or epiblem. This view appears to be reasonable because its origin, function and structure differ from those of the shoot. In other words, the rhizodermis or epiblem is neither homologous with (in terms of morphology and structure) nor analogous with (in terms of functions) the epidermis of other organs. Therefore, the terms rhizodermis or epiblem is adopted here.

Depending upon the persistence or permanence of this layer the rhizodermis becomes suberized or cutinized or the outermost layer or layers of the cortex lying immediately beneath the rhizodermis may be differentiated into layer of cells with suberized walls. A layer of this kind is known as exodermis. The exodermis develops after the original rhizodermis is sloughed off. When present this may consist of one to several layers of cells. According to some authors this is supposed to represent the hypodermis in a topographical sense although it is both histochemically and structurally specialized.

A typical characteristic of the rhizodermis is its capacity to develop root hairs. The root hair region is just one to few centimetres away from the tip. A root hair develops as a direct prolongation of some or all of the rhizodermal cells (Fig. 2.29). If it is formed from a special cell distinct in size from the neighbouring cells it is known as the trichoblast.

Cortex: This region of the root is delimited outwardly by rhizodermis and inwardly by endodermis. Cortex usually consists of homogenous layers of parenchyma. The arrangement of parenchyma cells may be radial and concentric (Fig. 2.29, ;2.33) or loosely arranged. The cells are frequently associated with

intercellular spaces. The cortex shows variation with respect to the subterranean environmental conditions of the habitats For example, in wet or marshy habitats the cortex develops air cavities which are formed either schizogenously (by separation of cell walls along their middle lamella) or lysigenously (by disorganization of existing cells) (Fig. 2.33) or rexigenously (by tearing of cells). Sometimes the arrangement of air cavities formed by the disintegration of the radiating rows of parenchyma cells conforms to radial alignment similar to that of the latter. (Fig. 2.33). In the case of monocotyledonous sclerenchyma is developed to varying number of layers either in the outermost cortex or next to the endodermis (Fig. 2.34). In palms isolated fibre bundles are scattered in the cortex. Starch is often present.

Endodermis. This represents a single layer of structurally specialized cells and is located on the innermost limit of the cortex (Fig. 2.29; 2.30). The endodermis is present quite characteristically and universally in all roots of different kinds. Each endodermal cell is characterized by a strip of thickening on its anticlinal (radial) walls and it is known as the Casparian strip or band (Fig. 2.30; 2.31). The thickness and the prominence of the thickenings vary according to the stage of development of the endodermis. In roots undergoing secondary growth, the endodermis is either crushed or stretched or totally discarded or developing further in order to keep pace with the expanding vascular cylinder. But at the same time in the absence of any secondary growth as in the majority of monocotyledons and a few dicotyledons, the endodermis remains as such by undergoing changes only with respect to their own cell walls and not any other changes as mentioned above. The endodermal cells facing the phloem are thick-walled and those confronting the protoxylem elements possess only Casparian strips on their anticlinal walls. Such cells are called 'passage cells' through which the materials pass between the cortex and vascular cylinder. It should be remembered that an endodermis is wanting in stems and other serial organs and even if present the one possessing all the above mentioned characteristics is absent

Pericycle: This is usually present as a single layer of parenchyma cells internal to endodermis (Fig. 2.30). But in the case of monocotyledons lacking secondary growth, the pericycle is com-

posed of thick-walled cells (Fig 2.34) The pericycle is also known as the pericambium because of its subsequent meristematic activities concerned with the development of lateral roots, phellogen or cork cambium and cambium in roots showing secondary growth. Pericycle is always present in roots except in those of water plants and parasites. Apart from its meristematic activities, the pericycle is supposed to represent the outermost limiting layer of the stele (the central cylinder of the axis comprising the vascular system and the associated ground tissue) and also as a layer which is part and parcel of the stele on the basis of their common origin with stelar components.

Vascular cylinder (stele): The vascular tissue together with ground tissue represented by pericycle, interfascicular regions and pith comprise what is known as the central cylinder of the axis (stem and root) or stele. The stele is recognized as a morphologic unit of the plant body. The vascualar tissues in a young root are represented by primary xylem and primary phloem. In contrast to the stems they are quite characteristically arranged not in the same radius but on different radii. In other words, the primary xylem and primary phloem regularly alternate with each other (Fig. 2.29; 2.30; 2.33; 2.34). This kind of arrangement is known as the radial arrangement which is a characteristic feature of all the roots just as the reverse condition known as collateral arrangement is characteristic of the stems Under this radial arrangement, the vascular tissue occurring in the form of discrete strands occupy the peripheral part of the vascular cylinder or stele and in which case the central part of the root is distinctly recognizable as parenchymatous pith (Fig. 2.29). In another from the root stele the xylem strands alone project into the centre thereby forming a central xylem core and in which case a distinct parenchymatous pith is absent. Another anatomical distinction between the root and stem is observed with respect to the relative position of xylem elements, namely protoxylem and metaxylem elements within each strand. In all roots the elements of protoxylem lie near the periphery and abutting on the pericycle, while those of the metaxylem, a little away from the latter (towards the centre). Likewise the elements of protophloem and metapholem of primary phloem reveal similar positional relationships. The xylem having this kind of orientation is known as exarch which is an universal characteristic feature of all roots. The reverse arrangement of proto-

xylem and metaxylem elements known as endarch condition is an inevitable feature of all stems. This particular anatomical feature together with radial arrangement of xylem and phloem stand out not only in contrast to the reverse situation (endarch xylem and collateral arrangement of vascular tissues) present in the stems but the said features are useful and dependable in the matter of identification of these two organs under any circumstances. The first formed elements of vascular tissues represent the protoxylem and protophloem poles respectively. Based on the number of protoxylem poles, the roots are designated as monarch (one), diarch (two), triarch (three), tetrarch (four) (Fig. 2.29), pentarch (five) and so on. Each one of these said conditions represents the usual feature of the dicotyledonous roots. When the number of protoxylem poles is greater than these numbers as noticed in most of the monocotyledons such roots are said to be polyarch (Fig. 2.32). The number of xylem strands in a given root although emphasized as a sure mark of distinction between the monocots and the dicots does not hold good since it is seen to be frequently variable depending upon the level of observation and examples. In this respect compare the primary structure of root of *Ricinus communis* with that of *Chloris barbata* and their respective figures thereof. (Fig. 2.29; 2.30; 2.33; 2.34).

Description of Primary Structure of a Dicotyledon Root— *Ricinus communis L.* (**castor**) (Fig. 2.29; 2.30)

Diameter of the root described is about 0.8 m.m. The outline of the root is somewhat circular. There is a single layer of rhizodermis or epiblem (for adoption of these terms in lieu of epidermis, see above) which is equivalent to the epidermis of other authors. The rhizodermal cells are variable in size and shape. The cells possess thin walls somewhat radially elongated and compactly arranged. Cortex is very broad and constituted of parenchyma cells with intercellular spaces among them. Endodermis is represented by a single compact continuous layer of cells which are rectangular or squarish in shape, variable in size and possess Casparian strip of thickenings on their radial walls. Pericycle is also a single layer of compactly arranged parenchyma cells varying in size and shape. Vascular system: In terms of number of protoxylem poles the root is tetrarch. There are 4 groups of strands of primary xylem regularly alternating with similar

number of primary phloem groups. As the primary xylem and primary phloem occupy separately alternating radii the arrangement is said to be radial. As far as the orientation of the protoxylem elements is concerned the xylem is exarch (protoxylem element is nearer to the periphery than that of the metaxylem which is close to the centre). As mentioned earlier the radial arrangement of the components of the vascular tissues and the exarch xylem which are the tell tale marks of the roots are present in this example. The primary xylem elements are somewhat angular in outline. The metaxylem elements are broader than those of the protoxylem and the former are arranged in a biseriate manner. Each primary xylem strand contains 6-8 radial rows of elements as seen in transection. A gradual reduction in the diameter of the elements commencing from the central metaxylem elements towards the peripheral protoxylem elements may be observed thus indicating difference in this respect between them. The primary phloem contains sieve elements and companion cells which appear smaller than the surrounding cells. Furthermore, they are somewhat polygonal in outline and compactly arranged. The ground tissue (pith) is parenchymatous, the cells of which are thin-walled, somewhat variable and compactly arranged.

Description of the structure of a Monocotyledon Root—

Chloris barbata Sw (Kodai pullu; Sevaragu pullu; common grass). (Fig 2.33; 2.34)

Diameter of the root described is 0.9 - 1.0 m.m. *Rhizodermis* consists of thin-walled cells which are variable in size and shape and some of them develop unicellular rhizoids. *Cortex* is recognizable into 3 zones; the outer zone consists of 2 layers of tangentially elongated somewhat thick-walled sclerenchymatous cells; the middle zone is broad and characterized by several air-cavities which are formed as a result of the dissolution of rows of parenchyma cells (lysigenous origin). It may be noted that the development of air-cavities is rather gradual, and progressive depending upon the age of the roots. In very young roots they are absent but instead the entire cortex is solid composed of parenchyma and the cells of which are all arranged in radiating rows. Since the air-cavities are lysigenously formed at a later stage at the expense of the parenchyma

which is present in radiating rows their disposition also conforms to similar pattern. Furthermore the air-cavities are separated by radiating rows of parenchyma (unaffected). The inner cortex consists of 2 layers of narrow tangentially elongated cells. *Endodermis* is single layered. Cells are rectangular with uniform thickening throughout ('O' type). *Pericycle* is made up of single layer of cells which are larger than those of the endodermis. The cell walls are thick unlike those of the pericyclic cells of the dicotyledon roots *Ground tissue* is sclerenchymatous and some of its cells contain tannin. *Vascular system.* The primary xylem and primary phloem contain 5 units in each and they are radially arranged but a little away from the pericycle. Metaxylem vessel elements are rounded in outline having a diameter of 20 μ. ($1 \mu = 1/1000$ m.m.) Protoxylem elements are not easily distinguishable. Metaphloem consists of 2-3 sieve tube elements in each unit and as many companion cells.

PHYSIOLOGY OF THE ROOT SYSTEM

In general, the normal functions of roots are:

1. Anchoring the plant firmly to the substratum
2. Absorption and conduction of water and mineral salts
3. Storage of food

I. Anchorage

'Plants that are growing in the ground need roots for being anchored to the substratum, otherwise they would be blown over by the wind. Roots penetrate the ground and branch to fix the plant firmly in the soil.

II. Absorption of water

Plants are in need of large amount of water for performing various functions. Water is absolutely essential for the metabolic activity of protoplasm. Water acts as a solvent for different kinds of salts and gases and it is the medium in which most of the chemical reactions of living protoplasm occur. Water is one of the raw materials needed for photosynthesis. Turgidity of cells necessary for growth, requires water.

Land plants absorb water from the soil mainly through roots. Aquatic plants absorb water throughout their surface. The absorption of water does not take place from the entire surface of the root. Only younger portions of the root near the tip absorb water and mineral salts.

Near the tip of a young root, four distinct regions or zones are distinguishable At the extreme tip is the root cap which covers the growing point. Just above the root cap is the meristematic region, where maximum cell division occurs. Behind this, is the zone of elongation where the root grows in length. Above

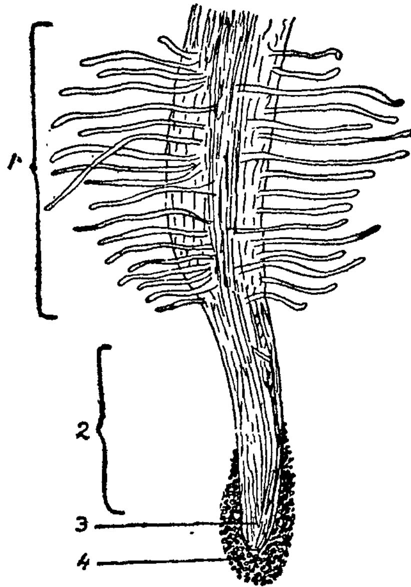


Fig. 2.35 Tip of a young root showing the different zones
1. Root hair zone 2. Zone of elongation 3. Meristematic zone 4. Root cap

this region there is a zone which bears the root hairs. The root hairs are the main organs of absorption of water. Behind the root hair zone lies the mature parts of the root (Fig. 2.35).

A root hair is a tubular unicellular outgrowth of the peripheral wall of an epidermal cell of the root. The cell wall of the root hair is made up of cellulose. It encloses cytoplasm which

contains a nucleus. The cytoplasm forms a lining layer immediately inside the cell wall. There is a large vacuole in the centre. The vacuole is filled with cell sap which is a solution of salts and organic

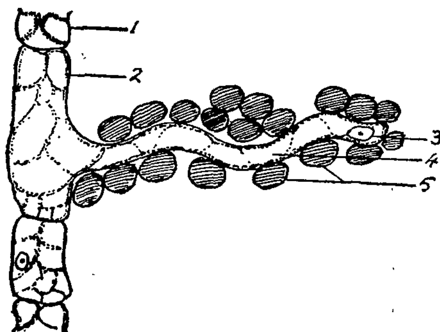


Fig. 2.36 Structure of the root hair
1. Cell wall 2. Cytoplasm 3. Nucleus 4. Vacuole
5. Soil particles

acids dissolved in water. The wall of the root hair is mucilaginous and therefore it sticks firmly to the soil particles (Fig. 2.36).

Root hairs are short-lived structures. As old root hairs die, new root hairs continue to develop in the younger part of the root. They come in contact with new supplies of water in the soil by growing between soil particles which are surrounded by soil water.

Absorption of water by the root hair takes place chiefly by means of a physical process called osmosis and to some extent by imbibition.

Imbibition

Imbibition may be defined as the soaking up of a liquid in solid materials, particularly in dry or semi-dry condition. The cell wall and the protoplasm absorb water by imbibition. The swelling of dry seeds in water and the swelling of doors and other wooden frame work during rainy season are common examples of imbibition. Imbibition can occur only if there is an affinity between water and the material Thus rubber does not imbibe water but imbibes benzene

Osmosis

Osmosis is the process of diffusion of a solvent (water) from a region of higher concentration to a region of lower concentration through a semipermeable membrane. This can be demonstrated by a simple experiment.

A thistle funnel with a long stem is taken and a sheep's bladder, which is a semipermeable membrane, is tied round the mouth of the thistle funnel tightly. The funnel is filled with sugar solution. It is inverted and kept immersed in a beaker containing water. The initial level of the sugar solution in the stem of the funnel is marked and the set up is kept undisturbed. After sometime, the level of the sugar solution in the stem of the funnel rises. This indicates that water from the beaker has entered into the funnel through the sheep's bladder

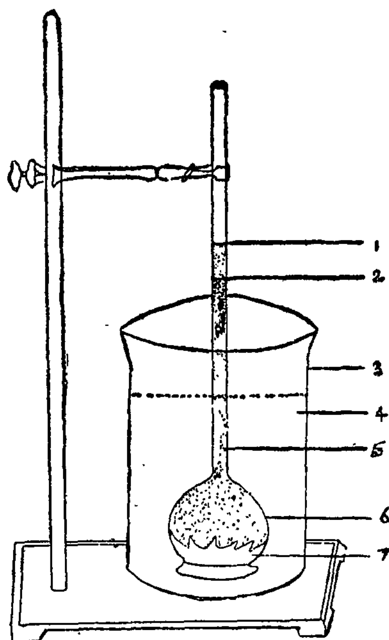


Fig. 2.37 Experiment to demonstrate osmosis

1. Final level 2. Initial level 3. Beaker 4. Water 5. Sugar solution 6. Thistle funnel 7. Sheep's bladder

Sheep's bladder is a semipermeable membrane and allows only water molecules (solvent) and not the molecules of sugar

(solute) to pass through it. The concentration of water in the beaker is greater than that in the funnel. According to the laws of diffusion, particles of different concentrations move in such a way as to equalise the concentration throughout. Thus more number of watei molecules move from the beaker into the thistle funnel than those that move from the funnel to the beaker. Such passage of water through a semipermeable membrane is called osmosis (Fig. 2.37).

A comparison between the thistle funnel experiment and the root hair is helpful in understanding osmosis in plants.

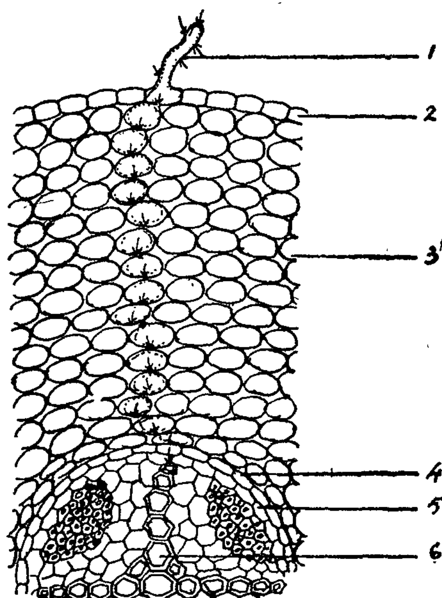


Fig. 2.38 T.S. of root showing the path of water from the root hairs to the xylem
1. Root hair 2. Piliferous layer 3. Cortex
4. Endodermis 5. Pericycle 6. Xylem

The thistle funnel may be compared to the root hair and the sheep's bladder, to the lining layer of cytoplasm of the root hair. The sugar solution in the funnel corresponds to the cell sap and the water in the beaker, to the soil water. The cell sap in the root hair is, under natural conditions, of a higher salt concentration than soil water. Therefore water is taken in by the root hair through osmosis.

There are several factors that affect water absorption by roots. These factors are environmental and internal. The environmental factors are (1) availability of soil water, (2) soil temperature, (3) concentration of soil solution and (4) aeration. Transpiration, metabolism etc., are the internal factors.

When water enters the root hair from the soil, the concentration of water in the cell sap of the root hair becomes higher than that of the cell sap of the inner cortical cell. Hence water from the root hair enters the outermost cortical cell by osmosis. In the same manner it passes through many layers of cortical cells, endodermis and pericycle and finally reaches the xylem vessels. Due to osmosis, a pressure is set up in the root. This is called root pressure which helps in the upward flow of sap. (Fig. 2.38)

Root pressure can be demonstrated by mercury manometer experiment.

A well watered pot plant is taken. Its stem is cut off under water about an inch or two above the soil level. A mercury mano-

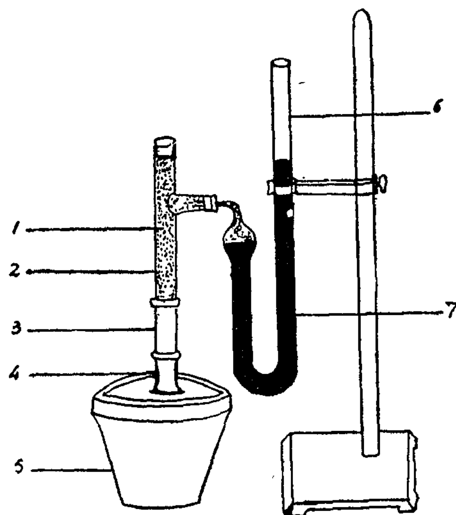


Fig. 2.39 Root pressure experiment
1 Water 2 Glass tube 3. Rubber tube 4 Stem
5 Pot 6. Manometer 7. Mercury

meter is attached to the cut end by means of a rubber tube. Care is taken to see that water completely fills the rubber tube up to

the level of mercury in the manometer. The mercury level in the open end of the manometer is noted and the set up is left undisturbed. After a few hours it will be noticed that the level of mercury at the open end of the manometer has risen up. Evidently sap exuding from the cut end of the stem forces the mercury upward. The exudation of water is due to root pressure By finding the maximum height to which mercury is lifted, the root pressure of the plant can be calculated (Fig. 2.39).

III. Storage

Roots also serve for the storage of food. Roots which become swollen and fleshy due to the storage of food materials are called root tubers. In radish, beet root, carrot, etc., the tap root serves this function. In *Asparagus*, sweet potato, etc., adventitious roots serve as storage roots. Many of the root tubers are edible. Both the cortex and the vascular cylinder may be places of food storage. Roots may also store water

ECONOMIC IMPORTANCE OF ROOTS

Roots are useful in many ways for our food, and medicine. They are also useful in extracting the tannin materials and dyes which are widely used nowadays in leather and textile industries

I. Food

Root vegetables are commonly used in food preparations.

1 *Sweet Potato*: (*Ipomoea batatas*—Convolvulaceae family) It is one of the oldest crops of tropical countries. It is a herbaceous perennial with weak stem trailing prostrate on the ground. The twin adventitious roots end into fleshy tubers. There are two types namely red and white. This can be cultivated in all types of soil but grow well in sandy and lighter soils.

(*a*) The tuberous roots are an important source of starch Besides starch, it contains some sugar, vitamin A, B and C

(*b*) It is also used for laundry starch and in paper and textile industries, confectionery, bakeries and in the manufacture of cosmeties and adhesives.

2. *Beet-root*: (*Beta vulgaris*. Family Chenopodiaceae).

The plant is a native of Europe and is very well cultivated in India. It is a biennial herb with large fleshy tap-roots.

Beet-roots are rich in carbohydratres proteins, minerals and A, B and C vitamins.

3. *Carrot.* (*Daucus carota* Family Umbelliferae).

The plant is a biennial herb with fleshy conical tap-root. It is cultivated as a winter crop in India. It can be grown in all types of soil except clay. It is highly nutritious and contains caroteins, thiamine, riboflavin, vitamin C, D and E. phosphorous and calcium.

4. ***Radish*** (*Raphanus sativus* Family Cruciferae).

It is a native of Europe but is widely cultivated in India. It is a biennial herb with white or reddish tuberous tap-root.

Roots and leaves are taken as vegetables.

II. Medicine

Roots are also extensively used in the preparation of allopathic and Indian systems of medicine.

1. *Rauwolfia serpentina*: (Family Apocyanaceae).

This is commonly known as serpagandha due to its serpent like roots. It is found in the rain forests of India. It is a small erect herbaceous plant.

Dried roots contain reserpine and rescennamine alkaloids.

It reduces blood pressure.

It is successfully given in the state of mental anxiety, hypertension and fear It is also used to cure mental illness.

2 *Colchicum autumnale* (Family Liliaceae).

It is a herbaceous plant found in the Himalayas. The roots of the plant are used for diseases of liver, spleen, rheumatism. When the drug is applied externally, it reduces the pain and inflammation. Colchocine extracted from the root is widely used to induce polyploidy, thereby producing improved varieties of plants.

3. *Ferula asafoetida*: (Family Umbelliferae)

This is a small herbaceous plant from the cooler parts of India. It is a perennial herb. Asafoetida is extracted from the roots. It aids digestion and it is also used as a pain reliever and laxative.

III. Tannin

This is a substance obtained from various plants and it is widely used in the leather industry. Some of the tannins are extracted from the roots of plants like *Geranium wallichiana* and *Rumex hymenocephalus*.

IV. Dyes

Dyes are colouring matters which are obtained from the roots of some plants. They are chiefly used in the textile industry and also for colouring paints, varnishes, leathers, paper, wood, food, cosmetics, etc.

A red dye is extracted from the roots of *Mallothosphillipinensis* and an yellow dye from the roots of *Morinda tinctoria*.

Chapter III

THE SHOOT SYSTEM

A. STEM

The shoot system is the ascending portion of the axis of the plant, developing directly from the plumule. It consists of the stem which bears leaves, branches and flowers.

Characteristics of the stem

1. Stem grows away from the centre of gravity (negatively geotropic) and towards sunlight. (positively heliotropic).
2. When young it is normally green in colour.
3. The growing apex is covered over and protected by a number of young leaves which arch over it.
4. Stem often bears hairs of different kinds.
5. It branches exogenously.
6. It is provided with nodes and internodes.
7. It has got axillary and terminal buds.

Habits of plants

The habit of the plant is determined by the nature of its stem and the maximum height attained during its life time.

1. *Trees*: These are large plants with a single stout trunk. The trunk and its branches are *hard* and *woody*. They are capable of growing to great heights). (*e.g.*,) Mango, Coconut (without branches).

2. *Shrubs*: These are shorter than trees. They do not have a tall and thick trunk. A number of branches grow crowded together from near the ground, giving the plant a bushy appearance. (*e.g.*,) *Hibiscus rosasinensis*, Bamboo.

3. *Herbs*: These are small plants with soft stems. (*e.g.*,) *Ruellia tuberosa*, paddy.

Duration of plants

Plants are classified into four groups according to their life span and the nature of giving rise to flowers and fruits.

1. *Annuals*: are plants which complete their life-cycle within a year or season, within this period they grow, reproduce and die (*e.g.*,) Mustard (*Brassica juncea*), Paddy (*Oryza sativa*)

2. *Biennials*: are plants which will live for two years. They attain their full vegetative growth in the first year and produce flowers and fruits in the second year, after which they die off (*e.g.*,) Carrot, Radish and Beet-root.

3. *Perennials*: are plants which will live for a number of years and give flowers and fruits every year. Since these plants bear flower and fruits many times, in their life-time, they are said to be Polycarpic (*e.g.*,) Tamarind, Mango.

Turmeric, Ginger are herbaceous perennials. The aerial parts of these plants may die down every year at the end of the flowering season, but next year, again new shoots develop from their underground stems. Thus they live for a number of years.

Functions of the stem

1. *Conduction*: The water and mineral salts absorbed by the root system will be conducted upwards through the stem to the various other parts of the shoot system like branches, leaves, etc. The food materials prepared by the leaves is conducted downwards through the stem to the roots and other storage organs.

2. *Support*: The stem supports the branches and leaves in such a way that they are exposed to the sunlight and atmospheric air to derive maximum benefit from both. Stem also supports fruits and seeds for effective dispersal.

3. *Storage*: Generally all the stems, store food materials in their *cortex* and *pith*. But some of the aerial stems like Sugarcane and underground stems like Ginger and Turmeric store large quantities of food materials in their stems.

4. *Vegetative propagation*: Underground stems like Ginger and Turmeric and aerial stems like Rose and Jasmine are useful for multiplication without the help of their seeds which is known as vegetative propagation.

CLASSIFICATION OF STEMS

During the germination of the seed, the shoot system develops from the plumule portion of the embryo. So in the majority of the plants, the shoot system and consequently the stem is seen above the soil. Such aerial stems are called *epigeous stems.* In some plants in addition to the epigeous stems, there are stems found below the surface of the soil. They are described as *underground stems.*

Epigeous stems

Epigeous stems are further subdivided into *erect stemmed plants* and *weak stemmed plants.*

Erect stemmed plants: The stems of these plants are generally strong enough to stand erect and support the branches. (e.g.,) *Leucas aspera, Casuarina.*

Weak stemmed plants: In some plants the aerial stem is thin, weak and unable to stand erect. The weak stems of such plants may either lie horizontally on the ground and are called *weak stemmed horizontal plants.* Weak stemmed plants which make use of supports for erecting themselves are known as *climbing plants.*

I. Weak stemmed horizontal plants

The stems of these plants are weak and so they are unable to stand erect. They grow horizontally along the soil. These may be further divided into the following types. (1) Prostrate, (2) Decumbent, (3) Runner, (4) Sucker, (5) Stolon, (6) Off-set.

Runner: There is a main stem fixed to the soil, with a number of leaves clustered together. An axillary bud grows out into long slender branch having long internodes. This branch spreads itself horizontally on the surface of the soil. At each node leaves arise on the upper side and adventitious roots are developed from the basal portion of the node. Thus a little daughter plant is formed at each node. This daughter plant is capable of leading an independant life even if it is cut off from its mother plant. Such a slender horizontal branch, giving rise to new plants at the nodes is called a runner.

(*e.g.,*) *Hydrocotyle asiatica, Oxalis corniculata* (Fig. 3.1).

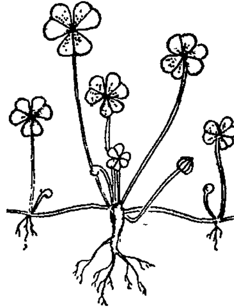


Fig. 3.1 Runner

II. Climbing plants

These are weak stemmed plants which stand erect with the help of supports. These are classified into three types.

A. Twiners

B. Climbers

C. Lianes

A. Twiners

Twiners are weak stemmed plants which make use of their stems for climbing by twining round a support. These twiners have slender stems with long internodes. The apex of the stem exhibits a regular circling movement (circumnutation) which enables it to twine around a suitable support. If a circling tip touches a suitable support, it twines and creeps upwards round the support. At first, there are only loose coils which will be tightened up later on by subsequent straightening of the stem. These changes are brought about mainly by the gravity, though contact stimulus also plays a little part with it. Only after the twining is completed the leaves of the stem expand fully.

The direction of the twining may be constant and specific. If it is clockwise it is called *dextrose* as in *Dolichos lablab* and when it is anticlockwise it is called *sinistrose* as in *Clitoria terratea*

B. Climbers

The climbers are provided with special organs to help them in climbing. They are given various names according to the nature of the climbing organ.

(1) Tendril climbers
(2) Hook climbers
(3) Thorn stragglers
(4) Root climbers

1. *Tendril climbers:* Tendrils are slender, spirally coiled spring like structures. They are highly sensitive to contact and when they come across any support they coil round the support. They are not independent organs of the plant. They represent some organ of the plant that is modified to help the plant in climbing.

(*a*) In *Cissus quadrangularis* the terminal bud is modified into the tendril (Fig. 3.2).

(*b*) In *Passiflora* the axillary bud is modified into tendril (Fig. 3.3).



Fig. 3.2
Cissus quadrangularis



Fig. 3.3
Passiflora



Fig. 3.4
Lathyrus

(*c*) In *Lathyrus* the entire leaf is modified into tendril (Fig. 3.4).

2. *Root climbers:* In pepper and betel-vine,aerial adventitious roots are developed at the nodes which are useful for climbing (Fig. 2.14).

C. Lianes

In tropical rain forests there are large woody-climbers which grow to greater heights. They are rooted in the soil, but twine around the support so as to reach the top of the branches of the tall trees. They may not have special climbing organs. (*e.g.,*) *Bauhinia vahlii.*

UNDERGROUND STEMS

In some plants underground stems are found to do certain special functions like storage, vegetative propagation and perennation. The advantages of the underground stems are:

(*a*) Since the plants store their food materials in their underground stems, it will be safe and is not available to the grazing animals.

(*b*) Underground stems can store more food materials than the epigeous stems.

(*c*) In many plants with underground stems, the aerial portion of the stem dries up during the end of the growing season, while the underground stem stay alive to give rise to new plants on the advent of favourable season. Thus the underground stems are useful as organs of perennation.

(*d*) There are several buds in an underground stem which may develop into many new plants quickly. So these are useful for vegetative propagation also.

Root tubers and underground stems

Root tubers and underground stems are swollen and fleshy due to the storage of food materials. But underground stems can be easily distinguished from the root tubers by the following characteristic features.

1. There are nodes and internodes in underground stems similar to the aerial stems. But these are absent in root tubers.

2. There are many adventitious roots present in underground stems.

3. There are no green photosynthetic leaves in the underground stems, but there are brown small leaf like structures

without green coloured pigments. Since these leaves are not useful for photosynthesis they are called *scale leaves*. Such scale leaves are absent in root tubers.

4 Terminal buds and axillary buds are found in the underground stems which are normally absent in the root tubers. But in sweet potato there are buds which do not belong to neither axillary or terminal buds.

There are four important types of underground stems:

1 Rhizome

2. Corm

3. Tuber

4. Bulb

1. *Rhizome* · Rhizome is an underground main stem which grows horizontally under the surface of the soil. Due to the storage of food materials, it is short and fleshy. It is divided into nodes and internodes and bears brown scale leaves at their nodes. In the axils of scale leaves, there are axillary buds. There is also a terminal bud found at the apex of the rhizome. From the lower surface of the rhizome there are many adventitious roots which fix it to the soil.

The terminal bud of the rhizome develops into aerial green shoot system with green leaves and flowers. At the end of the

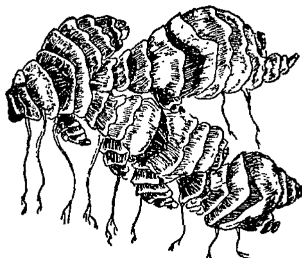


Fig 3.5 Rhizome

growing season the green aerial shoot system dies out and further growth of the rhizome is said to be sympodial (e.g.,) Ginger (*Zingiber officinale*) Turmeric (*Curcuma longa*) and *Canna indica* (Fig. 3.5).

2. *Corm:* Here undergfround stem is not horizontal as in rhizome. This is also a main stem like rhizome. It is quite massive, swollen and slightly spherical due to the storage of focd materials. There is a long terminal bud at the apex of the corm. There are also numerous scale leaves surrounding the terminal bud, each having a small bud in its axil. The corm is attached to the soil by numerous adventitious roots.

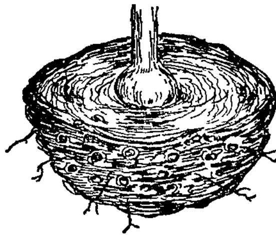


Fig. 3.6 Corm

Under favourable conditions, the terminal bud develops into a green aerial shoot. (e.g.,) *Amorphophallus campanulatus. Colacasia antiquorum* (Fig. 3.6).

3. *Tuber:* This is the swollen end of a special underground branch. This arises from the axil of a leaf, grows horizontally and ultimately swells up at the apex. It is greatly swollen due to

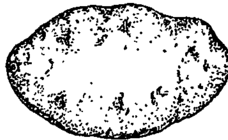


Fig. 3.7 Tuber

the heavy deposit of reserve food materials e.g., Potato. (*Solanunt tuberosum*). In this there are several structures known as 'eyes'. Each eye represents a node with the scar of the scale leaf and a depression containing the axillary bud. The eyes are spirally arranged on the tuber which is also having a terminal bud at its apex. Under favourable conditions the buds in the eyes develcp into aerial shoot system with adventitious roots (Fig. 3.7).

4. *Bulb:* The bulb consists of an underground modified shoot consisting of a very much reduced stem., which may be conical or convex in shape. There is also a terminal bud covered over by a number of fleshy scale leaves. The scale leaves grow from the upper surface of the stem, while a cluster of adventitious

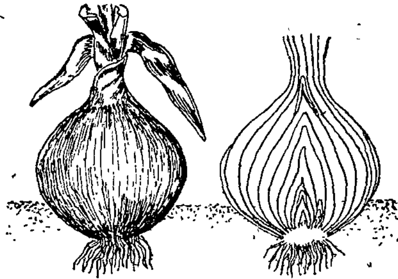


Fig. 3.8 Bulb

roots are given off from its base. While the inner scale leaves are fleshy the outer ones are dry as in onion (*Allium cepa*). The scale leaves are arranged in concentric manner and covered over by dry scale leaves. So the bulb is described as tunicated (Fig. 3.8).

In Scilla the scale leaves are not arranged in a concentric manner as in onion; but simply overlap one another by their

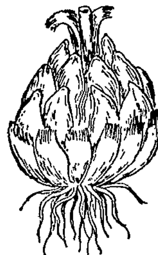


Fig. 3.9 Naked

edges. There are no dry scale leaves as in onion. Such bulbs are described as naked (Fig. 3.9).

AERIAL MODIFICATIONS OF STEM

The normal stem is erect, green in colour when young and brown when old. Its normal functions are support and conduction. In addition to these normal functions, stems may also perform certain special functions and for this they are variously modified.

Cladode: If the stem is modified to become a flattened green structure doing the function of the leaf, it is known as *phylloclade.* If it consists of one internode only it is described as a *cladode.* But many Botanists treat both the terms as synonymous.

Phylloclades and cladodes are found in *xerophytic plants,* which grow in places where the available water is minimum. This is combined with the increase in temperature and dry atmospheric air. Plants found in such *habitats* try to conserve the water absorbed by their root system. They also try to check the excessive evaporation of water which takes place through transpiration. In doing so, the plant parts are variously modified. Such modifications brought about by the special conditions of the habitat are known as *adaptations.*

Opuntia dillenii is a xerophyte growing in dry habitats. The shoot system consists of several discoid segments which are flattened, green and leaf like. They are fleshy, storing large quantities of water. This is mixed with a substance called *mucilage* which prevents the easy evaporation of water. The flattened stem is green and does the function of the leaf. The leaves are small and fall off early (caducous). There is a thick cuticle found on the setm.

On the flattened stems, there are raised portions called *tubercles,* where the canducous leaves are present. There are a number of spines on the tubercle The spine bearing area of the tubercle is called *areole* There are two kinds of spines Some of the spines are stiff and strong and the others are slender, barbed bristles. These spines protect the stem portions from the grazing animals. Other examples are *Euphorbia tirucalli, Euphorbia antiquorum, Cerius Muehlenbeckia* (Fig 3 10)

In *Asparagus* the cladodes are needle like and arise in clusters in the axil of a scale leaf on a long shoot (Fig. 3.11).

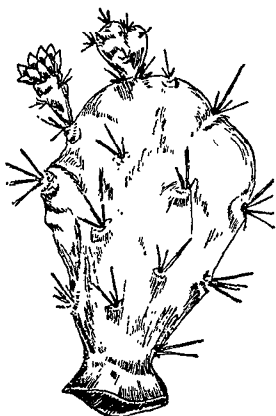


Fig. 3.10 Opuntia dillenii

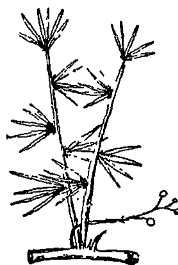


Fig. 3.11 Asparagus

ANATOMY OF THE STEM

From the anatomical standpoint, the aerial axis of vascular plants (possessing xylem and phloem as vascular tissues) is known as the stem. The stem bears leaves and flowers. The stems may be simple, solitary without branches and short lived as in the case of many herbaceous annuals or woody bearing several branches, leaves and flowers and long lived as in trees and shrubs. In certain cases the stems become modified and remain underground in the form of bulbs (*Allium cepa*—*Onion*), rhizome (*Zingiber officinale*—Ginger), corm (*Amorphophallus campanulatus*—Yam) or modified branches in the form of tuber (*Solanum tuberosum*—Potato). However the stems both normal and modified, are marked by nodes and internodes, the former are recognized as the leaf bearing loci. The leaves usually develop buds in their axils known as the axillary buds which may be active or remain dormant depending upon their physiological conditions The whole stem together with all its leaves represent the shoot system of a plant. The trees show sympodial or monopodial growth and in the case of the former the activity of the terminal buds is limited and further growth is assured and carried over by lateral or axillary buds. Under such

circumstances the growth form ultimately results in a spreading type (*Ficus bengalensis* —Banyan tree). In the case of the monopodial type of growth the terminal buds are more active and continuous than the lateral or axillary buds and thus finally giving rise to a tall cone like or pyramidal growth form (*Pinus strobus*—The Pine, *Cocos nucifera*—The coconut).

The stems just like the roots are constituted of three major tissue systems when considered in the broad sense namely the dermal, the fundamental and the fascicular or vascular systems The variations in the primary structure of the stems of different species seem to be in the first place due to relative quantum distribution of the fundamental and vascular tissues and sometimes such variations are further enhanced by the presence of certain types of idioblasts (special cells within a tissue markedly differing in form, size, structure and contents from the remainder of the same tissue), etc. In the dicotyledons the vascular system of an internode (nodes not considered here for the present because of their different anatomical construction) when considered in its three dimensional aspect appears to be delimited by the non-vascular tissues externally by cortex and internally by pith and thus the vascular system as such is in the form of a hollow cylinder (Fig. 3.12; 8.12). The vascular system in the case of a dicotyledon may be continuous without any apparent subdivision and gaps in between (Fig 8.12) or subdivided into certain number of discrete units being separated by gaps (regions occupied by non-vasular tissues (Fig. 3.12; 8.12). Each one of the units is known as the vascular bundle or fascicle as seen in transverse sections but when considered with reference to the axis as a whole it is in the form of a vertical strand anastomosing with each other here and there throughout its course as observed in longitudinal aspect The intervening area or gap (parenchymatous) between any two units is known as the interfascicular area and it is occupied by parenchyma. This area is also often called the medullary of pith ray since it appears to radiate from the pith or medulla of a stem (Fig. 3.12). On the other hand most of the monocotyledons reveal a more complex arrangement particularly with respect to the number and pattern of distribution of the vascular bundles. When observed in transections they do not usually appear in the form of a ring of vascular bundles as in the case of a young dicotyledon stem but appear to be distributed throughout the transection

of the stem thereby the usual distinction between the pith and cortex is lost or becomes less precise (Fig. 3.20). Although the pattern of arrangement (regular *versus* scattered) and the number of vascular bundles (limited *versus* unlimited) are usually said to be the marks of distinction between the stems of dicotyledons and monocotyledons, these presumed criteria many a time fail and hence to be followed with caution (*see* elsewhere). Because there are a few dicotyledons showing the so-called monocotyledonous stem structure and *vice versa* On the other hand features such as the absence of a vascular cambium in the vascular bundles (closed condition) and the presence of bundle sheaths are characteristically seen in the stems of monocotyledons. Therefore these features may be emphasized as contrasting with those of dicotyledons and employed for the purpose of distinction.

The primary structure (young), secondary structure (old) of the stem and the structure of the leaf of a dicotyledon plant are explained with the help of *Ricinus communis* L. (castor bean) and the internal structure of stem and root of a monocotyledon plant with the help of a common grass, *Chloris barbata* Sw (kodai pullu, sevarugu pullu)

Primary Structure—*Ricinus communis* L. (transection of internode) (Fig 3.12; 3.13).

Diameter of the internode examined is 1.9 mm *Cuticle* is rather thin and uniform in thickness and smooth. *Epidermis* consists of a single layer of cells which are somewhat radially elongated. The cells are compactly arranged without intercellular spaces The epidermis remains intact in all the primary organs but during the process of secondary growth taking place in the concerned organs, it is replaced by a secondary protective layers. *Hypodermis* consisting of 5-6 layers of collenchyma, the cells of which are characterized by thickenings at their corners and known as angular collenchyms. Cells appear rounded in transections. *Cortex* consists of about 6 layers of thin walled parenchyma cells which are variable in size and shape and arranged with intercellular spaces and most of them containing chloroplasts and hence called chlorenchyma. *Vascular bundles* 13 in number, discrete, separated by broad zone of interfascicular parenchyma and arranged in the form of a single ring thus representing an eustelic condition. Vascular

bundles varying in size, oval shaped, open because of the presence of vascular cambium which is single layered but apparently appearing more than 1-layered; the initials are radially narrow, thin-walled, slightly tangentially elongated and arranged more or less in regular tiers. *Primary xylem* endarch, containing both protoxylem and metaxylem elements. Protoxylem elements being the first formed ones are characterized by annular or helical thickenings or both annular and helically thickened elements are present (Fig. 8.9); the elements are narrow and considerably elongated and situated nearest to the centre of the axis; sometimes the very first formed elements of the protoxylem may become crushed thus giving rise to proto-xylem lacuna (Fig. 3.13). The metaxylem elements on the other hand being the later formed ones subsequent to the differentiation of the protoxylem elements and the organs concerned cease their elongation which are characterized by thickenings in the form of scalariform, reticulate and pitted types (Fig. 8.9). Furthermore these elements, unlike those of the protoxylem, are broad and short. However both these elements are arranged in radial rows. The primary xylem elements are associated with parenchyma. *Primary phloem* contains protophloem and metaphloem and they are recognized just as in the case of primary xylem on the basis of time of appearance and sequence of differentiation. The protophloem elements develop and differentiate first as the organs undergo rapid elongation and because of this situation the elements concerned are narrow and considerably elongated. With respect to the position, the protophloem elements occupy the outer limits of each vascular bundle. Further-more the sieve areas are difficult to recognize because of the greater length of the elements (sieve tube members) and the companion cells and phloem parenchyma may be absent. They function only for a brief period and in the case of rapidly elongating organs, they are destroyed (obliteration) or differentiated into fibres. The sieve tube members of the metaphloem on the other hand are broader and relatively short because they develop and differentiate after the cessation of the elongation of the organs concerned. Unlike the sieve tube members of the protophloem those of the metaphloem are characterized by the presence of distinct sieve areas, companion cells and phloem parenchyma. The metaphloem lack fibres and retain activity for a longer period. The metaphloem is nearest to the vascular cambium. The vascular bundles

containing both primary phloem and xylem arranged on the same radius are called collateral bundles which are characteristically seen in all the serial organs. *Pith* is broad, and parenchymatous the cells of which are thin-walled and arranged with intercellular spaces. *Idioblasts* are commonly present in the pith particularly in the cells adjoining the vascular bundles; secretory cavities of schizogenous origin (originating by separation of cell walls) being surrounded by a regular rosette of cells are common in the neighbourhood of primary phloem and sometimes in the pith.

Status of Endodermis and pericycle: The endodermis which is typical in the roots of dicots and monocots is wanting in the stems (Compare Figs. 3.12; 3.13 with 2.30 and 2.34). In those few cases an endodermis like layer is observed which is nothing but a specialized layer containing starch and therefore such a layer is known as starch sheath or endodermoid layer. Likewise the pericycle which is so characteristically present in the roots of both dicots and monocots is absent in the stems. What appears as and is generally supposed to be a pericycle in certain stems is in reality nothing but a layer of fibrous cells. Secondly, while the pericycle of the roots is capable of becoming meristematic and giving rise to derivatives in the dicotyledons at the commencement of secondary growth, the so-called pericycle of the stems consisting of a layer or layers of dead cells is thus incapable of giving rise to any derivatives. From the foregoing it may be concluded that the root pericycle is both structurally and functionally different from the so-called stem pericycle

Differences between young stems and roots

Cuticle is present over the epidermis of the stems and it is wanting in that of roots. The typical endodermis and pericycle are absent in stems but present in roots. The xylem and phloem of stems are arranged in the same radius thus becoming collateral with endarch xylem but in roots they are spacially separated and aligned in different alternating radii with exarch xylem. Stomata and different kinds of epidermal hairs which are usually present in stems are lacking in roots but instead unicellular root hairs are present in the latter. (Compare Figs. 2.29; 2.30; 2.33; 2.34 with 3.12; 3.13; 3.18; 3.19).

Structure of a Monocot Culm (Stem)—*Chloris barbata* Sw. —(Fig. 3.18; 3.19). *Diameter* of the culm described is about 2.7 mm. The outline of the culm in transection appears to be somewhat circular or oval shaped. Cuticle is rather thin and uniform throughout. *Epidermis* cells are isodiametric and possess thick walls. *Hypodermis* consist of 10–12 layers of sclerenchyma which forms continuous layers but interrupted by several sclerenchyma strands and islands of assimilatory tissues (chlorenchyma). Each one of the assimilatory tissues consists of fairly large cells filled with starch grains and chlorenchyma cells. Sclerenchyma strands are triangular shaped. *Ground tissue* is represented by parenchyma, the cells of which progressively become large towards the centre and are arranged with intercellular spaces. *Vascular bundles* are 33–35 in number and are distributed peripherally in an irregular manner. In addition to these large bundles, several smaller bundles are embedded in the hypodermal sclerenchyma. These smaller vascular bundles are not only circular in outline but arranged to form a regular ring and in contrast to this situation the large bundles are usually oval shaped and distributed in an irregular manner. However each vascular bundle is collateral with endarch xylem and represents the closed type. All the vascular bundles are surrounded completely by 1–2 layers of sclerenchyma known as the circumvascular sclerenchyma. The number of metaxylem vessel elements per vascular bundle varies from 2–3, arranged more or less in a transverse line. Protoxylem lacuna is usually present in all large vascular bundles. Metaphoem is characterized by fairly large sieve tube elements and each one of them is laterally associated with a companion cell.

SHOOT SYSTEM (PHYSIOLOGY)

Functions

The functions of the stem are support, translocation, storage and propagation.

I. Support

The chief functions of the stem is to support the leaves and flowers and spread them out on all sides for proper functioning —the leaves to get sufficient amount of sunlight for photosynthesis and the flowers to get pollinated.

II. Translocation

The stem conducts water and mineral salts upward from the root system to the aerial portion of the plant and food manufactured in the leaves downward to regions where it is used or stored. This process whereby water and food move through the plant is termed conduction or translocation.

The water containing mineral salts absorbed from the soil by the roots is known as sap. The sap is conducted upwards to the leaves and the growing regions of the stem and the branches. In herbaceous plants, the height to which this water has to reach is small. Some trees like Australian Eucalyptus, Sequoia and some conifers attain a height of 100 metres or more. In these the sap has to be lifted to a great height. The upward movement of water and dissolved substances is called the ascent of sap.

Path of movement of sap

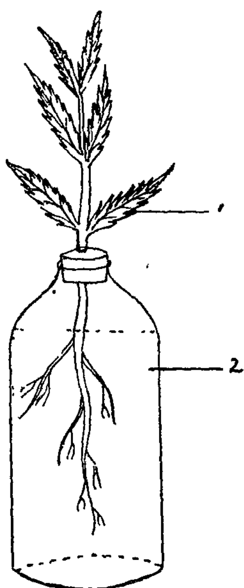


Fig. 3.20 Experiment to demonstrate the path of sap
1. Balsam plant 2. Eosin solution

The sap ascends in the plant through the xylem. This can be demonstrated by a simple experiment.

A small herbaceous plant namely Balsam, is carefully uprooted and its root is kept immersed in a bottle containing water coloured with eosin. After sometime streaks of red colour will be seen along the whole length of the stem and also in the veins of leaves. If cross and longitudinal sections of the stem at different levels are taken and examined under the microscope, it is found that only xylem is stained by eosin. This shows clearly that ascent of sap takes place only through xylem vessels (Fig. 3.20)

Another experiment known as Ringing or Girdling experiment also proves that the ascent of sap takes place only through xylem. Two plants are taken. In one plant, all the tissues external to the xylem for a distance of about an inch are removed in the form of a ring (or girdling) from a branch without injuring the xylem.

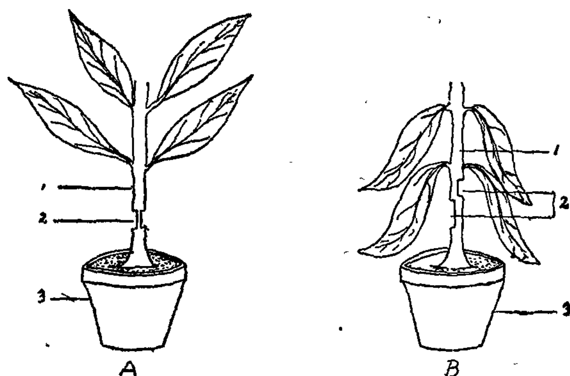


Fig. 3.21 Girdling or Ringing experiment

A—1. Plant 2. All the tissues external to xylem removed 3. Pot
B—1. Plant 2. *Continuity of xylem intercepted* 3. Pot

In another plant, the continuity of xylem tissue is broken by making two opposite half cuts a short distance apart in a branch. In the former case the leaves of the branch remain fresh and do not wilt. In the latter case, the leaves of the branch wilt in a short time. *Thus the removal of a ring of tissue external to the xylem does not interfere with the upward movement of water but the break in the continuity of xylem stops conduction of sap.* This shows that the ascent of sap takes place through xylem (Fig. 3.21).

III. Storage

The stem frequently serves as an important storage organ. It may become modified for food manufacture, water storage etc. Many plants manufacture more food than what is made use of. A large part of this surplus is stored in the stem. A stem is a better storage organ than an ordinary leaf as the former is usually a more permanent structure. Moreover it is of advantage to the plant that the surplus food manufactured in the leaves is removed from them so that food material does not accumulate and interfere with its continued production.

IV. Propagation

Plants have developed certain ways by which they can propagate themselves for the continuation of their race. Subaerial stems like runner and underground stems like rhizome, tuber etc., propagate vegetatively. The underground stems are provided with buds. These buds are capable of quick and vigorous growth by using the stored up food materials. New individuals can also be artificially produceed through layering, cutting and grafting.

ECONOMIC IMPORTANCE OF STEMS

From very early times man has been using the stems of many plants in various ways. In fact he is being called a 'civilized man' only after he made use of many economically important plant products.

1. Food

Many of the underground stems and some of the aerial stems of herbaceous plants are used as vegetables.

(*a*) *Potato.* (*Solanum tuberosum. Family solanaceae*)*:* Potato is one of the most important food plant of the world. It is a native of America and is cultivated widely in India.

The plant is an annual herb with underground tubers. It contains 18% of carbohydrates 78% water, 2% proteins and only 1% of fat. It is also used in the preparation of starch and alcoholic beverages.

(*b*) *Colocasia esculenta.* (*Family Araceae*)*:* This is a perennial herb which is cultivated in warm humid regions of our country. It contains carbohydrates, proteins, some minerals like calcium phosphorus, and a few vitamins.

It is used as a vegetable. Its flour is used in making breads, biscuits and soups. Industrial alcohol is prepared after fermentation.

(*c*) *Allium cepa and Allium sativum.* (Family Liliaceae): Both are bulbous biennial herbs cultivated largely in India. Both contain carbohydrates, proteins, calcium, phosphorus, iron, and vitamins A, B and C.

2. Sugarcane. (*Saccharum officinarum*, family Gramineae)

Sugarcane is cultivated in India since prehistoric times. The plant grows best in moist hot and sunny places with an average rainfall of 50 to 60 inches per annum and an optimum temperature of 75 to 80°F. It can best he grown in loamy soil with sufficient mineral matter.

It contains glucose, sucrose, proteins, organic acids, pectins and vitamins. The sugarcane breeding station in Coimbatore has evolved many new varieties of sugarcane which are cultivated throughout the world.

3. Rubber

There are many rubber yielding plants out of which *Hevea braziliensis* (family Euphorbiaceae) is very important. It is a native of South America successfully introduced in India. The plant is a tall evergreen tree growing to a height of 60 to 150 feet and it will live for 200 years. It is grown, in well drained loamy soil with an annual rainfall of 80 to 120 inches and 75 to 90°F.

Shallow incisions are made in the bark of the tree and the milk is collected and purified.

India rubber is obtained from *Ficus elastica* of Moraceae. But this is of inferior quality.

Rubber is used in making tyres, tubes of cycles, motorcycles and cars. It is also used to make shoes, belts, toys, cushions, gloves, water proof cloths etc.

4. Timber

Timber is obtained from large trees and it is variously used.

(*a*) In building houses, for pillars, doors and windows the timber used is obtained from teak (*Tectona grandis*)

Rose wood (*Dalbergia latifolia*), Mango tree (*Mangifera indica*) etc.

(*b*) Furniture and almirahs are made from *Cedrela toona Albizzia lebbeck*. etc.

(*c*) Agricultural implements are made from *Thespesia populnea, Acacia catechu* etc

(*d*) Toys for children are made from *Morinda tinctoria Santallum album etc*

(*e*) Wooden sleepers for railways are obtained from *Xylia xylocarpa* and *Mesua ferea.*

(*f*) The wood of *Bombax malabaricum* and *Heritiera tarretia* are used to build boats.

(*g*) The wood of *Ailanthus malabaritum* and *Bombax malabaricum* are used in the preparation of matches.

(*h*) The musical instruments like Veena, Mirudhangam and Kanjira are made from Jack. (*Artocarpus integrifolia*) and *Cedrela toona.*

Fibres

(*a*) Linen cloth is prepared from the fibres obtained from the stem of *Linum usitatissimum.*

(*b*) Artificial fibres like rayon and viscose for cloth making are obtained from the timbers of *Eucalyptus. Abies* etc.

(*c*) Fibres obtained from *Corchorus capsularis,* and *Corchorus olitorius* are used to make the jute. Fibres are also obtained from *Hibiscus cannabinus* and *Cannabis sativa.* These fibres are useful in many ways.

Medicine

The stems of many plants are useful in the preparation of many allopathic and indigenous medicines.

(*a*) *From Chenopodium Umbrosioides* medicine is prepared to remove the worms from the alimentary canal.

(*b*) From the bark of *Cinchona officinalis*, Quinine is obtained and it is given for malarial fever.

(*c*) Medicine prepared from *Strychnos nux-vomica* is useful as a muscular relaxtant and to remove the hypertension of the nervous system.

7. Tannin

Tannin is a substance which is very useful in the leather technology. It is an organic compound with many *Glucosoides*. It is obtained from many plants such as *Acacia arabica*, *Acacia dealbata*, *Cassia auriculata* and *Rhizophora mucronata*.

8. Dyes

Natural dyes are obtained from several plants.

(*a*) *Acacia catechu*, *Acacia arabica*, *Ventilago maderaspatana* give dyes useful for cotton and woollen fabrics.

(*b*) The yellow dye obtained from *Curcuma longa* and red dyes obtained from *Pterocarpus santalinus*, *Erythrina-indica*, *Mallotus phillippinensis* are used to colour the medicines, cloth, footwear etc.

(*c*) The red dye obtained from *Caesalpinia braziliensis* is useful in the preparation of red ink.

9. Paper

It is manufactured from *Bambusa arundinacea* and *Ochlandra travancorica*.

10. Sandal wood oil

It is obtained from the wood of *Santalum album* which is useful in the preparation of soaps and perumes.

B. LEAF

(MORPHOLOGY)

The leaf is regarded as the flattened, lateral outgrowth of the stem or the branch. It develops from the superficial tissues of a node (exogenously) and has a bud in its axil. In this respect, the leaf is regarded as a partial stem or branch, having a limited growth Leaves develop in an acropetal order on the stem. They are normally green in colour and are the most conspicuous organs of a plant.

Functions of the Leaf

1 *Photosynthesis*. The structure of the leaf is such that it is very well exposed to the sunlight and atmospheric air. With the help of the green coloured pigments present in the leaf, water, carbon dioxide and sunlight, leaf is able to synthesize its own food material and the process is known as photosynthesis.

2. *Respiration:* There are small openings found on the *epidermis* of the leaves called *stomata,* through which exchange of gases take place. During respiration, oxygen is taken in and carbondioxide is given off. This is done by all living cells and is said to be a *vital phenomenon.* During photosynthesis, Carbon-dioxide is taken in and oxygen is given off.

3. *Transpiration*: Plants absorb more water than is required. So the excess of water is evaporated through the stomata in the form of water vapour. This process indirectly helps the plant in the absorption of water and mineral salts.

In addition to the above mentioned important functions, some of the leaves also do certain other special functions like climbing, storage, etc; and are also useful for vegetative propagation.

Majority of the plants have green foliage leaves by which they prepare their own food materials and are said to be *autotrophic.* Such green foliage leaves are absent in *heterotrophic plants* namely the *parasites* and *saprophytes.* Parasites are plants which depend upon other living organisms for their food. (e.g.,). *Cuscuta.* Saprophytes are plants which derive their food materials from dead organic matter. (e.g.,) *Orabanche.*

PHYLLOTAXY

The mode of arrangement of the leaves on the stem is called *Phyllotaxy* and it varies in different plants.

1. *Alternate:* There is only one leaf at each node (Fig. 3.22)



Fig. 3.22 Alternate

2. *Opposite:* If there are two leaves arranged opposite to one another at each node, it is called opposite phyllotaxy. There are two variations in this type.

(*a*) *Superposed:* Such successive pairs of opposite leaves are all spread in one plane then it is known as super-



Fig. 3.23
Opposite and superposed

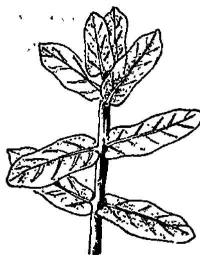


Fig. 3.24
Opposite and decussate

posed . When viewed from above all the leaves are found to lie in two vertical rows (Fig. 3.23). (e.g.,) *Quisqualis indica, Psidium gujava.*

(*b*) *Decussate:* If the successive pairs of opposite leaves are arranged at right angles to one another, it is termed decussate. (e.g.,) *Calotropis gigantia, Ixora* (Fig. 3.24).

3. *Ternate:* There are 3 leaves at each node. e.g., *Nerium* (Fig. 3.25).



Fig. 3.25 Ternate

4. *Whorled:* When there are more than 3 leaves at each node arranged in a circle, it is termed whorled. In *Allamanda* there are 4 leaves at each node. In *Alstonia* there are 5 to 7 leaves at each node (Fig. 3.26).

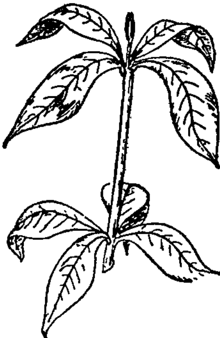


Fig. 3.26 Whorled

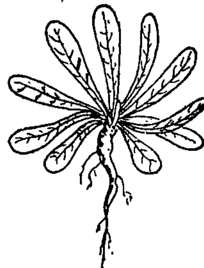


Fig. 3.27 Radical

5. *Radical:* Here the stem is condensed and short, found just above the soil level on which a cluster of leaves are arranged as in *Mollugo*. The leaves appear as though they start from the root directly (Fig. 3.27).

Significance of phyllotaxy

In order that the leaves may perform their functions efficiently it is essential that all the leaves should be well exposed to sunlight and atmospheric air. The various kinds of phyllotaxies help in

achieving this object and thus avoid over crowding and shading of the leaves by one another.

PARTS OF A LEAF

A normal foliage leaf consists of the following parts.

I Leaf base or *Hypopodium*

II. Petiole or *Mesopodium*

III. Leaf blade or Lamina or *Phyllopodium* (Fig. 3.28).

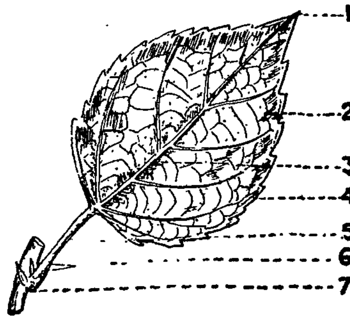


Fig. 3.28

1. Tip 2. Margin 3. Midrib 4. Lamina 5. Petiole 6. Stipule 7. Node

I. Leaf Base

The leaf base is the point of attachment of the leaf to the stem. In leguminous plants the leaf base is swollen and then it is known as *Pulvinus*.

In most monocotyledons, the leaf base becomes very prominent and winged. It is called a sheathing leaf base which clasps and covers the stem to a certain extent.

The leaf base sometimes bears a pair of lateral outgrowths called stipules.

Stipules: Stipules are lateral outgrowths found at the point of attachment of leaf with the stem. Plants with stipules are described as stipulate and plants without stipules are called exstipulate. Stipules are commonly present among the dicotyledons and they are rare among the monocotyledons.

Stipules may be shed early and described as *Caducous* as in *Michelia champaka.* If they remain for one season they are called *Deciduous* as in *Cassia tora.* If they remain as long as the foliage leaf, they are termed *Persistent* as in Rose.

II. The Petiole

In most of the leaves, petiole is present and it is described as *petiolate as* in Mango. The leaf without a petiole is called *sessile* as in *Calotropis.*

Normally the petiole is solid and cylindrical but sometimes it is modified.

1. In *Citrus* the petiole is flat and is called winged.

2. In *Clematis* the petiole is tendrillar and useful for climbing.

3. In *Eichhornia* the petiole is swollen and spongy enclosing much air and helps the plant to float in water

4. *Phyllode*: If the petiole is flat and green similar to the leaf it is described as a phyllode.

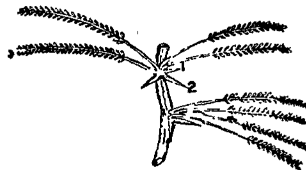


Fig. 3.29 Phyllode
1. Main rachis 2. Stipules

In *Acacia moniliformis* only phyllodes are present in the mature plant (Fig. 3.29).

III. The Lamina

The lamina is the most important part of the leaf as it performs, the most important physiological functions like photosynthesis respiration and transpiration.

The lamina is normally a flat structure. If it is differentiated into a definite upper and lower surface, it is described as dorsiventral (e.g.,) *Thespesia* In many Monocotyledons and in the plants growing in shady situations, the leaf is placed in such a manner, that both the surfaces receive equal light. There is no difference

between the two surfaces. Such leaves are called *isobilaterals* leaves (e.g.,) *Eucalyptus*. The leaf of onion is cylindrical and is termed as *centric*.

The lamina differs widely in different plants and they are studied from the following aspects.

A. Shape
B. Margin
C. Apex
D. Surface
E. Texture
F. Venation
G. Simple and compound leaf.

A. Shape of the Lamina

The shape of the lamina varies in a variety of plants. (Fig. 3.30).

1. *Linear*: longer and slightly broader as in many grasses.

2. *Lanceolate:* When the leaf is long and tapering at the end with the broadest part near the stalk and shaped like a lance as in *Nerium*, *Polyalthia*.

3. *Oblong*: When the blade is two or three times as long as it is broad, with parallel sides and the ends are rounded as in Musa (*plantain*) and *Ixora*.

4. *Elliptic:* The lamina is broadest at the middle with tapering ends and oval in shape as in Jack, *Vinca*.

5. *Ovate*: The lamina is slightly broader at the base than at the apex and is egg shaped as in Banyan.

6. *Obovate*: When the lamina is inversely egg shaped as in *Terminalia catappa*.

7 *Cordate:* When the lamina is heart shaped as in *Thespesia populnea*

8. *Deltoid*: When the lamina is broadly wedge shaped and triangular as in leaflets of *Erythrina indica*

9. *Sagittate*: When the lamina is similar to an arrowhead with two sharp straight lobes as in *Sagittaria* and *Arum*.

10. *Reniform*; When the lamina is bean shaped with a shallow depression at the base as in *Centella asiatica.*

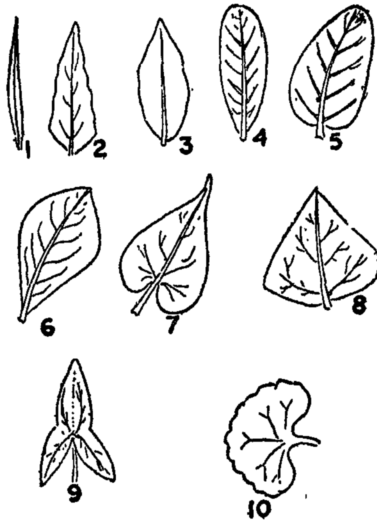


Fig. 3.30 Shapes of the leaf
1. Linear 2. Lanceolate 3. Oblong 4. Elliptic 5. Ovate 6. Obovate 7. Cordate 8. Deltoid 9. Sagittate 10. Reniform.

B. Margin of the Leaf

The margin of the leaf may be (Fig. 3.31).

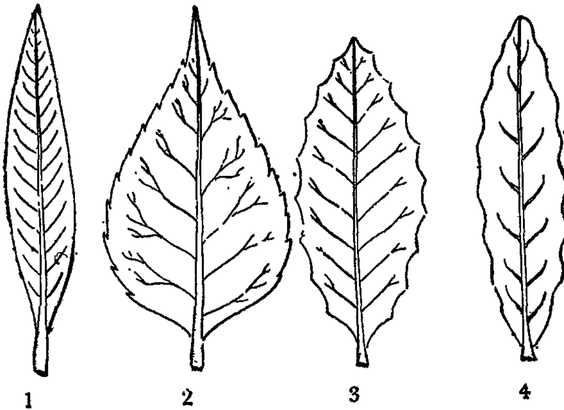


Fig. 3.31 Margin of the leaf
1. Entire 2. Serrate 3. Dentate 4. Undulate

1. *Entire.* When the margin is smooth as in Mango.

2. *Serrate*: When the margin is with teeth pointed towards the apex as in *Acalypha.*

3. *Dentate.* Margin toothed, the teeth are pointed out wards as in waterlily.

4. *Undulate*: Margin is wavy as in *Polyalthia.*

5. *Lobed*: When the margin is cut up into many lobes it is said to be lobed or incised.

C. Apex of the Leaf

The apex of the leaf differs widely in different plant (Fig. 3.32)

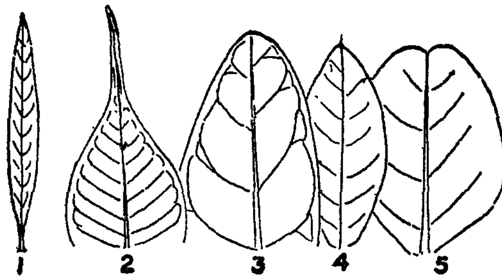


Fig. 3.32 Apex of the leaf
1. Acute 2. Acuminate 3. Obtuse 4 Mucronate 5. Retuse

1. *Acute*: the tip is sharply pointed as in Mango.

2. *Acuminate*: the tip is produced to a long fine point as in *Ficus religiosa.*

3. *Obtuse:* The tip is blunt as in Banyan.

4. *Mucronate*: The midrib is prolonged beyond the lamina as in *Cassia auriculata.*

5. *Retuse*: There is a round shallow depression at the tip as in *Calophyllum.*

D. Venation

In most leaves the petiole is continued into the lamina as *midrib* from which a number of lateral veins arise. The method

of arrangement of veins in a leaf blade is known as venation (Fig. 3.33).

Functions of the veins

1. They conduct water and mineral substances to all parts of the leaf.

2. They also conduct the prepared food materials to other parts of the plant.

3. They form the skeleton of the blade and help in keeping the blade rigid so that it does not get crumpled up or torn easily.

4. They help in keeping the blade flat, so that they may be fully exposed to sunlight.

Venation follows certain basic patterns. The Angiosperm leaf shows two principal types of venation.

I. Reticulate venation

II. Parallel venation.

I. Reticulate Venation

There is a strong midrib from which numerous branches are given off in all directions so as to form a net work covering the entire blade. This type is present in most of the dicotyledonous plants like mango, castor etc. Reticulate venation is of two types.

1. *Pinnately reticulate or Unicostate type:* In this type, there is a strong midrib or costa and it gives rise to a number of lateral veins towards the margin or apex of the leaf, like plumes in a feather. These are then connected by smaller veins which pass in all directions forming a network. eg. *Ficus bengalensis, Psidium guajava.*

2. *Palmately reticulate or multi costate type:* Here instead of a single main vein (midrib) there are a number of equally prominent veins which arise from the tip of the petiole and radiate outwards or upwards along the blade as the fingers spread out from the palm of the hand.

(*a*) *Divergent:* When the main veins diverge towards the margin of the leaf as in *Papaya, Cucurbita.*

(*b*) *Convergent*: When the veins converge to the apex of the leaf as in *Zizyphus jujuba.*

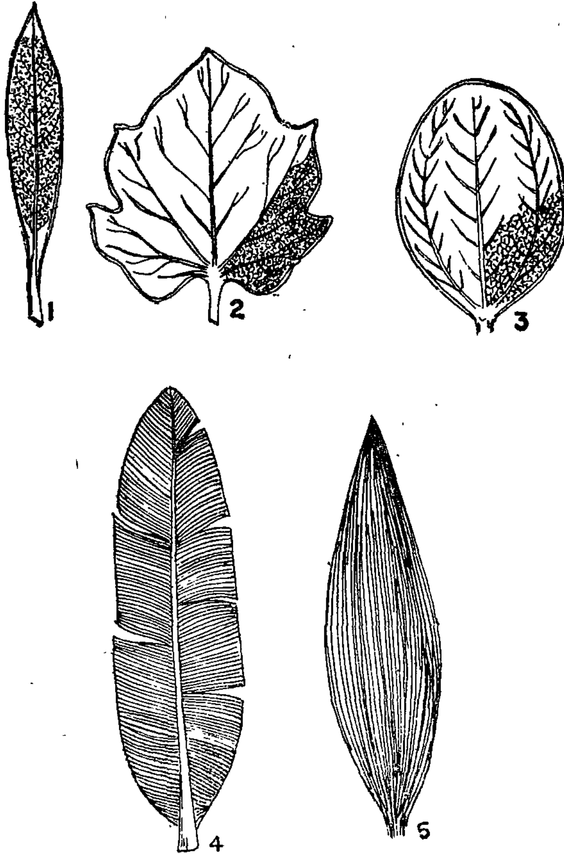


Fig. 3.33 Venation
1. Pinnately reticulate 2. Palmately reticulate, (Divergent)
3. Palmately reticulate (Convergent) 4. Pinnately parallel
5. Palmately Parallel (Convergent)

II. Parallel venation

When the veins are all more or less of the same size and run parallel to one another, the venation is said to be parallel. This type of venation is mostly seen in monocotyledons.

Parallel venation is of two kinds

1 *Pinnately Parallel*: In this type of venation the leaf has prominent midrib which gives off several lateral veins which proceed parallel to each other towards the margin or apex of the leafblade as in Banana, *Canna indica*.

2. *Palmately Parallel*: A number of veins start from the tip of the petiole and spread in the leafblade.

(*a*) *Divergent:* Starting from the petiole the veins radiate and spread out as in palmyra.

(*b*) *Convergent:* When a number of veins run parallel to one another along the length of the blade and converge at the tip as in Bamboo and grasses.

E. Simple and Compound Leaves

A leaf is said to be *simple* when it consists of a single blade attached to the petiole. This blade may be entire or undivided as in Mango or lobed as in cotton.

A leaf is said to be compound, when there is a main petiole bearing a number of blades, each having a small stalk of its own. The main petiole is known as rachis and each blade a leaflet. When the leaflets of a compound leaf are bigger, the leaf may look like a small branch bearing simple leaves. But the compound leaf may be distinguished from the branch by the following points:

1. The branch develops from an axillary bud of a leaf. There is an axillary bud in the axil of the main rachis of a compound leaf.

2. A branch will end in a terminal bud. A compound leaf has no terminal bud.

3. The simple leaves of a branch will have axillary buds in their axils The leaflets of a compound leaf do not have axillary buds.

4. A branch is always provided with nodes and internodes; while the rachis of a compound leaf is free from them.

Classification of compound leaves

The compound leaves may be broadly divided into

I. Pinnately compound leaves (Fig. 3.34)

II. Palmately compound leaves. (Fig. 3.35)

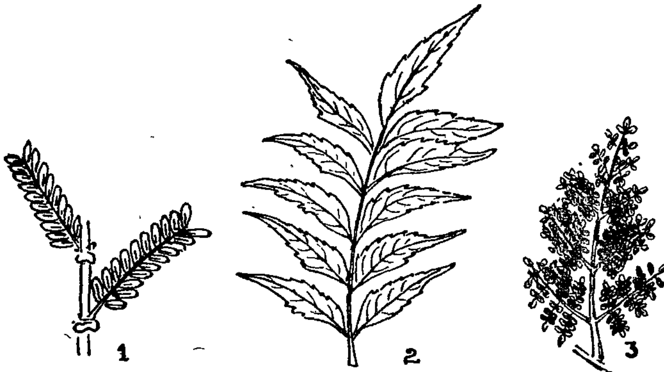


Fig. 3.34 Compound leaf
1. Paripinnate 2. Impari pinnate 3. Tripinnate

I. Pinnately compound leaf

In this type, the leaftels are arranged laterally all along the length of the rachis like the plumes of a feather. This may be further subdivided into many types.

1. *Unipinnate:* When the rachis of the pinnately compound leaf bears the leaflets directly, it is said to be unipinnate. There are two types under this:

(*a*) *Paripinnate:* when the leaflets are evenly arranged on the rachis and if the rachis ends in a pair of leaflets it is said to be paripinnate eg. *Cassia auriculata.*

(*b*) *Imparipinnate*: this is similar to paripinnate type, but the tip of the rachis ends in a single leaflet. (e.g) *Murraya exotica.* Rose.

In *Erythrina indica* there are three leaflets in a compound leaf. At first there are a pair of lateral leaflets on the rachis. Then there is elongation of the rachis which bears a single leaflet at its tip. This is referred to as trifoliate imparipinnate

2. *Bipinnate:* The compound leaf is twice pinnate i.e. the main rachis produces secondary rachii which bear the leaflets. (e.g) *Acacia arabica.*

3. *Tripinnate:* The leat thrice pinnate in the primary rachis gives rise to many secondary rachii and bears the leaflets. (e.g) *Moringa.*

4. *Decompound:* when the leaf is more than thrice pinnate, it is said to be decompound as in *Coriandrum sativum.*

II. Palmately compound leaf

The tip of the petiole bears terminally a number of leaflets radiating from a common point like fingers arising from the palm.

This may be further subdivided into a number of other types according to the number of leaflets.

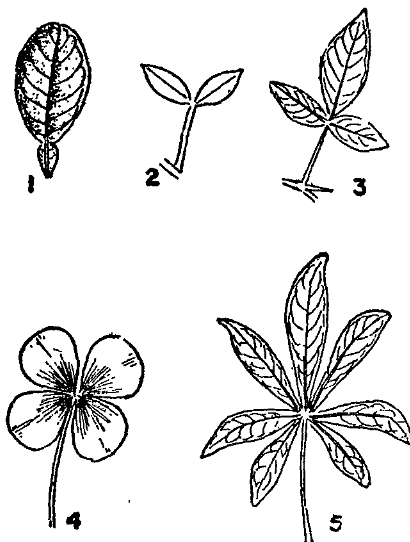


Fig. 3.35 Palmately compound leaf
1. Unifoliate 2. Bifoliate 3. Trifoliate 4 Tetrafoliate
5. Multi foliate

1. *Unifoliate:* when there is only one leaflet as in *Citrus*. This will appear like a simple leaf. But it is actually a compound leaf because there is a joint at the junction of the blade and the winged petiole.

2. *Bifoliate:* When there are two leaflets attached to the tip of the petiole as in *Bignonia grandiflora, Hardwickia binata*

3. *Trifoliate:* When there are three leaflets attached to the tip of the petiole as in *Aegle marmelos.*

4. *Tetrafoliate:* When there are four leaflets at the tip of the petiole as in *Oxalis tetraphylla.*

5. *Multifoliate*: There are many leaflets arising from the tip of the petiole like the digits of a palm as in *Bombax malabaricum.*

Modifications of lamina

In addition to the normal functions like photosynthesis respiration and transpiration the leaf blade or lamina does certain other functions also. In order to perform such specialised functions the lamina becomes modified or metamorphosed into distinct forms.

Specialised leaves as in insectivorous plants: There is a group of interesting plants known as insectivorous plants. They live in habitats where there is deficiency of nitrogenous substances. In order to compensate this these plants capture the small insects and derive nitrogenous substances from them.

Drosera: This is a small herbaceous plant with a rosette of spoon shaped leaves. The leaf blade consists of peculiar tentacles with swollen heads secreting a sticky glittering fluid. The fluid shines like dew in the sun and hence the plant in popularly

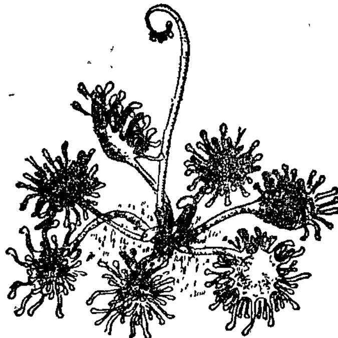


Fig. 3.36 Drosera

known as 'Sundew'. Small insects mistake this for honey and reach the leaf surface. The marginal tentacles bend downwards and

capture the insect. The glandular hairs surrounding the prey secrete the digestive juices and the insect is digested and absorbed. After the digestion is over the tentacles expand and are ready for another catch (Fig. 3.36).

THE LEAF

(Anatomy)

Leaf is an expanded flattened lateral organ or an appendage present at determined loci of the stems and branches known as the nodes. They are arranged in a particular manner with respect to a species. Leaves are of different kinds and are broadly classified into vegetative and floral leaves. The vegetative leaves represent cotyledons, scale leaves (cataphylls), various floral bracts (hypsophylls), prophylls (the first formed scale leaves of a lateral branch) and foliage leaves. Among these different kinds of leaves, the foliage leaves are the main photosynthetic organs of a plant although the remainder also takes part in photosynthesis to some extent. The first formed leaves of any plant emerging out of germination of the seeds are known as the cotyledons but they are only transitory organs. The scale leaves are usually protective and if fleshy do the storage function also as in *Allium cepa* (onion). Bracts are also usually protective in function but in certain cases by assuming colours other than green offer attraction to the organs enveloped by them. (ex. *Euphorbia pulcherrima* Willd.—*Poinsettia*). The foliage leaves are anatomically more differentiated and specialized than other kinds of leaves. They are characterized by the expanded flattened part known as the lamina, limb or blade which may be simple or compound (divided into certain number of smaller units called leaflets) and having a petiole (stalk) or not. Furthermore there are veins arranged in a particular manner (pinnate, palmate, parallel) and number characteristic of a species and they are particularly laterally inserted with respect to a central more prominent and stouter vein known as the midrib. As shown below the veins and midribs which are recognized in morphological sense represent in the anatomical sense the vascular system containing xylem and phloem within.

Just as the stems and roots consist of epidermis, ground tissue and vascular tissues when analyzed in the broad sense, the leaves also are characterized similarly by these tissue systems. On either side of the leaf, epidermis is present consisting of a single layer of cells known respectively as abaxial (lower) and adaxial (upper) epidermis. What is known as the ground tissue in the axial organs is present in the leaf as mesophyll tissue which in turn is differentiated into palisade and spongy tissues. The vascular tissue occur in the form of veins which are usually marked by profuse branchings and anastomosis depending upon their degree of development and the examples. The general anatomical characteristics of various foliar tissues and their respective functions may be briefly considered before the consideration of the internal structure of the leaf of *Ricinus cammunis* is attempted.

Epidermis: Trichomes (hairs) of different kinds are usually present. Sometimes the epidermal cells may also contain crystals. For other details, *see* under *tissues*.

Mesophyll: The mesophyll as mentioned earlier is considered to be equivalent to or homologous with the ground tissues of other organs. The mesophyll is usually differentiated into palisade and spongy mesophyll (Fig. 3.41). The palisade cells are slightly or conspicuously elongated radially thereby appearing cylindrical or rod like as seen in the transections of the leaf. They are aligned at right angles to the adaxial epidermis in the case of dorsiventral leaves and to both adaxial and abaxial epidermis in the isobilateral or unifacial leaves (leaves having similar structure on both sides). However, they present the appearance of a compact arrangement and seemingly developed of intercellular spaces in transection (Fig. 3.41). But in reality, the intercellular spaces are abundantly present, as could be seen clearly in the longitudinal sections of the leaves (Fig. 3.44). Leaves possessing the palisade tissue in the upper side and the spongy tissue in the lower side are known as the bifacial or dorsiventral leaves. If on the contrary the palisade tissues occur in both sides such leaves are called unifacial or isobilateral leaves as in *Nerium odorum* Soland. (Indian oleander). The number of palisade layers is variable ranging from 1–4 and the intercellular space system is much larger in it than in the spongy mesophyll. On the

other hand, the spongy mesophyll cells are irregular in size and shape. They are usually loosely arranged, coupled with conspicuous intercellular spaces and occupy more or less the lower half of the leaves, namely the abaxial half. Both palisade and spongy mesophyll cells are living and rich in chloroplasts, and thus they are qualified to function as the important and effective photosynthetic tissues. The mesophyll cells that are immediately adjoining and enveloping the vascular bundles are both structurally and functionally specialized and different from the remainder. They constitute the bundle sheath or border parenchyma (Fig. 3.41). This is also interpreted as equivalent to endodermis on the basis of its positional relationships with vascular bundles although the typical casparian strips are mostly indistinguishable in them (Fig. 3.41).

Vascular tissues: The vascular tissues are manifested externally and recognizable in the form of several veins. But in the anatomical sense as mentioned earlier, they represent vascular tissues which often show ramifications of first, second, third order and so on and anastomosis among them. The veins because of the frequent ramifications and anastoses subdivide the mesophyll ground tissue into a series of smaller polygons and thus resulting finally in the smallest subdivisions known as the areoles (Fig. 3.43). The ultimate veinlets or vein endings usually extend into and terminate in the areole (Fig. 3.43). The quantum of vascular tissues developed within a vein depends upon its order of development and its size. In other words, the larger veins such as the midrib contain greater amount of vascular tissues and the smallest veins the lesser amount. Thus a progressive reduction in the amount of vasculai tissues may be witnessed from the largest to the smallest veins. This kind of quantitative variation in the vascular tissues of the veins is accompanied by qualitative variation also. The vascular tissues as seen in the form of bundles in the transections of the leaves show xylem facing the adaxial (ventral) and phloem the abaxial (dorsal) sides (Fig. 3.41). This alignment is inevitable because the vascular tissues as they are departing and deviating from the stem undergo deflection in such a way that the xylem which is the innermost in the stem becomes the uppermost in the blade and the phloem which is the outermost in the former occupies the lowermost position in the latter. As far as

the midrib is concerned interesting variations of simple and complex nature pertaining to the number, size, shape, types and pattern of arrangements of vascular bundles may be observed. For example, the vascular bundles may be united forming a cylinder or in the form of discrete units arranged in the form of a ring or in the form of an arc (abaxial) confronted by an adaxial vascular bundle (*Ricinus communis*) (Fig. 3.37; 3.42) or not or the vascular bundles may be arranged in more than one ring or scattered, or they may have normal orientation or show torsion and inversion, etc. The smallest vein or the veinlet is reduced to such an extent that the xylem part of it usually contains tracheid and likewise the phloem part is represented by parenchyma instead of sieve elements. But in the case of larger veins both vessels and sieve elements are represented in full complement in the xylem and phloem parts of the vascular bundles.

Description of Transection of Lamina —*Ricinus communis* L. (castor bean) (Fig. 3.37; 3.38; 3.40; 3.41; 3.42).

The thickness of the lamina described is about 0.9 mm. Lamina is dorsiventral or bifacial. *Cuticle* is rather thin on either surface but thicker over the midrib. *Epidermis*: adaxial and abaxial epidermal cells are broad and variable in size and shape (Fig. 3.41) *Mesophyll* is differentiated into distinct palisade and spongy tissues, the former is about 2 layered The palisade tissue consists of elongated cells and are arranged perpendicular to the adaxial epidermis (in transverse section). They appear to be devoid of apparent intercellular spaces in transection (Fig. 3.41). The spongy tissue consists of more or less compactly arranged tangentially elongated, tabular cells, and showing little variation in size and shape (Fig. 3.41). The cells of both palisade and spongy tissues possess abundant chloroplasts (Fig. 3.41) and thus becoming essentially photosynthetic. Stomata occur in both adaxial and abaxial epidermis and hence called amphistomatic. The guard cells are 2 in number, rounded in outline and each one of them is characterized by a small horn like projection in its upper side known as outer ledge (Fig. 3.38). The guard cells are unevenly thickened and surrounded by a pair of subsidiary cells (Fig. 3.38). The substomatal chamber is narrow and small (Fig. 3.38). Midrib is prominent. This is adaxially ribbed and

abaxially keeled and appear broadly 'U' shaped (Fig. 3.37; 3.42). The abaxial and adaxial hypodermis in the midrib consists of 6–10 layers of angular collenchyma. The midrib ground tissue is constituted of colourless parenchyma cells and arranged with intercellular spaces. They contain abundant druses (Fig. 3.37).

Vascular system: This is represented by an abaxial arc of continuous vascular tissues and confronted adaxially by a solitary bundles (Fig. 3.37 ; 3.42). Primary xylem elements of the arc shaped strand are arranged in radial rows with protoxylem pointing towards adaxial epidermis and those of adaxial bundle towards the centre (Fig. 3.42). Primary phloem forms a continuous tissue on the abaxial side of the arc shaped strand and on the adaxial side of the solitary vascular bundle. The vascular bundles of laminal parts are rather small, rounded in outline and surrounded by colourless parenchyma cells forming bundle sheath (Fig. 3.41). The veinlet contains a single, solitary angular tracheid surrounded by chlorophyllous cells (Fig. 3.40). Idioblasts: druses are very abundant throughout the lamina particularly in the phloem parenchyma and the ground tissue of the midrib and in this respect, some of the palisade cells are enlarged to such an extent that they appear cyst like enclosing very large druses.

LEAVES

(Physiology)

The normal functions of leaves are (1) photosynthesis (i.e., manufacture of food) and (2) transpiration (i.e., evaporation of water). Besides these normal functions, leaves also do some other functions like storage.

PHOTOSYNTHESIS

The primary activity of green leaves is photosynthesis. Photosynthesis is the synthesis of carbohydrates from carbon dioxide and water by the chloroplasts making use of the energy of sunlight. It is also known as carbon assimilation since it results in the formation of compounds containing carbon. This process of photo-

synthesis is essentially the conversion of light energy into chemical energy of carbon compounds to be available for the life-processes of plants, animals and man.

Raw materials or Sources of material

The raw materials which react in photosynthesis are carbon dioxide and water. Water is absorbed from the soil by the roots and reaches the leaves through the xylem of stem. Carbon dioxide is obtained from the air that diffuses into leaves through the stomata. Carbon dioxide cannot enter the cells as gas. It dissolves in water present in the cell walls and this solution diffuses into the palisade and spongy cells of the leaf.

Chlorophyll

The chloroplast is the site of photosynthesis. It contains a green pigment called chlorophyll. Chlorophyll is not a single compound but it is a mixture of four different pigments namely chlorophyll (*a*), chlorophyll (*b*), carotene and xanthophyll. Chlorophvll does not contain iron but iron is necessary for the formation of chlorophyll.

Chlorophyll spectrum

Chlorophyll absorbs certain wavelengths of light. When a beam of light is passed through a glass prism, the light gets separated

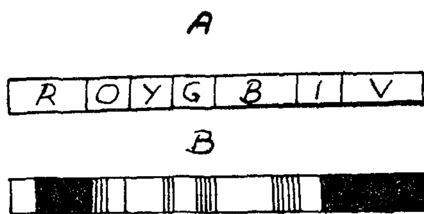


Fig. 3.45
A—Solar spectrum
B—Chlorophyll absorption spectrum

into different bands of colours, red at one end and violet at the other end and the remaining colours, indigo, blue, green, yellow and orange, in between these two. This is called a solar spectrum (Fig. 3.45).

If an extract of chlorophyll is placed in a glass container between the path of light and the prism, the normal solar spectrum is not formed. But dark bands appear in the regions of certain colours like red, blue and violet and less dark bands in the regions of other colours. This shows that certain wavelengths of light are partially or completely absorbed by the chlorophyll solution. Thus the chlorophyll absorbs more of certain colours of the wavelengths of light like red, blue, indigo and violet. These colours are used in the light reaction of photosynthesis. The dark bands are called absorption bands and the spectrum obtained by using chlorophyll extract is known as absorption spectrum of chlorophyll.

Factors affecting photosynthesis or conditions necessary for photosynthesis

The factors affecting photosynthesis may be classified into external and internal factors.

External factors

1. *Light*: Light is the most important factor for photosynthesis. It supplies energy necessary for photosynthesis. Photosynthesis will not take place in darkness. An increase in the intensity of light increases the rate of photosynthesis. But an excessively high intensity of light decreases the rate of photosynthesis.

2. *Carbondioxide*: Carbon dioxide is the source of the carbon for the organic substances formed in the plant. Plants obtain CO_2 from the atmosphere which contains only about 0.03% of the gas by volume. Higher concentration of CO_2 (above 1%) decreases the rate of photosynthesis.

3. *Water*: Water is necessary for photosynthesis as it is one of the raw materials in the process of photosynthesis. Palisade cells can carry on their function of food manufacture only when they are in a turgid condition for which water is essential. The amount of water actually used is very small. Yet its deficiency may decrease the rate of photosynthesis and also tend to close the stomata, thereby preventing the entry of CO_2 into the leaves.

4. *Temperature*: The optimum temperature i.e., the favourable temperature, for photosynthesis in most plants is 35°C. A further

increase or decrease in temperature affects the rate of photosynthesis.

Internal factors

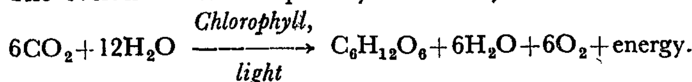
1. *Chlorophyll*: Chlorophyll is essential for photosynthesis. Chloroplasts function as photosynthetic organs only when they contain chlorophyll. Chlorophyll absorbs light energy and supplies the energy for the preparation of carbohydrates. Non-green plants do not have photosynthesising capacity.

2. *Protoplasmic factor*: There is some unknown factor within the protoplasm of the cell which affects the rate of photosynthesis. This unknown factor is probably enzymatic in nature and is called protoplasmic factor.

3. *Accumulation of end products of photosynthesis*: Usually food materials are translocated as soon as they are formed. Sometimes during photosynthesis, more food material is formed than what is translocated. This accumulation of end products may decrease the photosynthetic rate to some extent.

Chemistry of photosynthesis

The overall reaction of photosynthesis may be written as



$$6CO_2 + 12H_2O \xrightarrow[light]{Chlorophyll,} C_6H_{12}O_6 + 6H_2O + 6O_2 + \text{energy}.$$

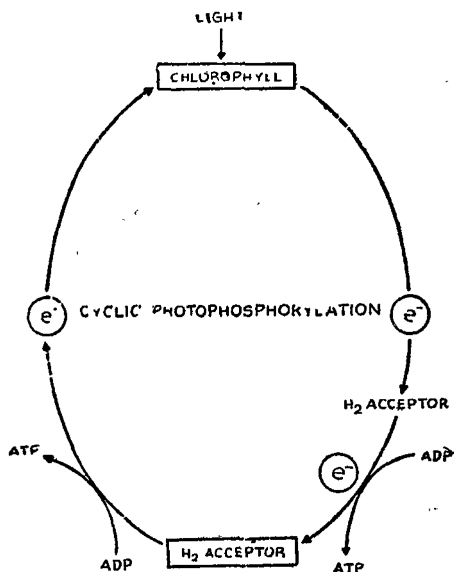
According to recent findings, photosynthesis occurs in 2 stages; (1) Light reaction and (2) Dark reaction.

Light reaction

This reaction takes place only in the presence of light and hence it is called light reaction. It is also known as *Hill's reaction* or *Photochemical reaction*. During this reaction, water is split up into hydrogen and oxygen by using light energy. This process is known as *Photolysis of water*.

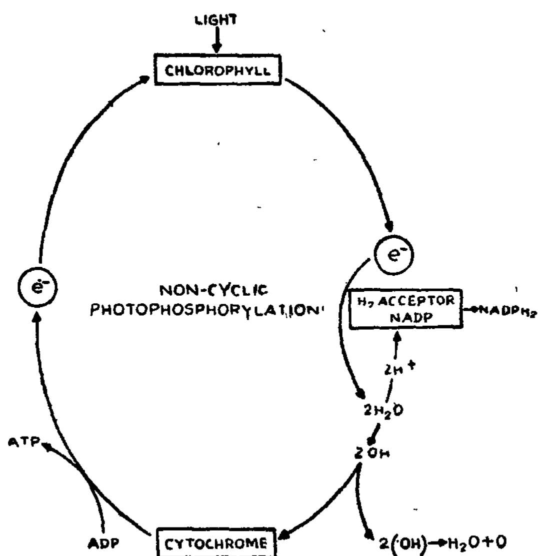
When light falls on chlorophyll, the chlorophyll molecule absorbs light energy and becomes excited or activated. This activated chlorophyll molecule releases an electron which is at high energy level. The electron moves from one hydrogen acceptor to another and during its movement, it releases energy. A

part of this energy is utilised for the formation of a high energy compound. Adenosine Triphosphate (ATP) and the remaining part of the energy is used for photolysis of water The process of formation of ATP in the chloroplast is known as photophosphorylation. The electron which is released from the activitated chlorophyll once again returns to the chlorophyll after transferring its energy to ATP Again the cycle is repeated. This type of electron transport is known as *cyclic electron transport or cyclic photophosphorylation* since it involves the formation of ATP also.



Some electrons are used for the splitting up of water i.e. for photolysis of water. Water is split up into hydrogen (H^+) ions and hydroxyl (OH^-) ions. Since hydrogen ion cannot remain in a free state, it is immediately taken up by a hydrogen acceptor called NADP (Nicotinamide Adenine Dinucleotide Phosphate). The NADP is now reduced to $NADPH^2$. Two hydroxyl ions combine to produce water and oxygen. The oxygen is released as gas. In this process, the hydroxyl ion also releases an electron. This electron is taken by a pigment called cytochrome. The cytochrome then donates this electron to chlorophyll. During the electron transfer ATP is formed. The electron released from the

chlorophyll does not return to the chlorophyll and the electron that returns to the chlorophyll is derived from another source (i.e.) from



hydroxyl ion of water. This type of electron transport is known as *non-cyclic electron transport or non-cyclic photophosphorylation.*

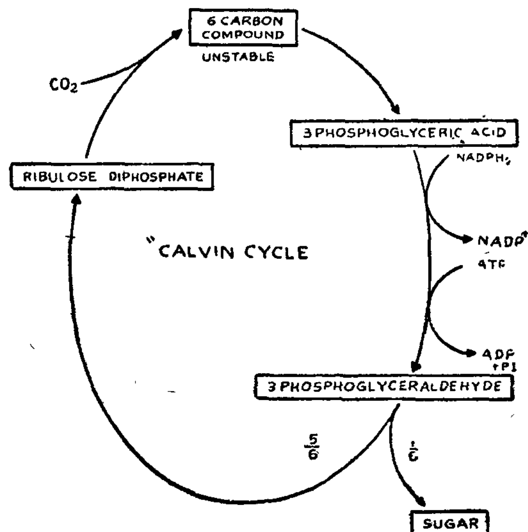
Dark reaction

This reaction does not require light and therefore it is called dark reaction. It is also known as *Blackman's reaction* or *Purely Chemical reaction.* This process involves the reduction of CO_2 to a carbohydrate and it is known as *Fixation of* CO_2.

First CO_2 combines with a 5 carbon compound namely Ribulose diphosphate present in the leaves to form a 6 carbon compound. This 5 carbon compound is not stable and therefore it immediately forms 6 molecules of a 3 carbon compound called phosphoglyceric acid. The phosphoglyceric acid is then converted into phosphoglyceraldehyde. The $NADPH_2$ and ATP formed during light reaction take part in the conversion of phosphoglyceric acid to phosphoglyceraldehyde. After this reaction,

$NADPH_2$ and ATP become NADP and ADP respectively.

Of 6 molecules of phosphoglyceraldehyde, one molecule forms the end product of photosynthesis. A part of it is utilised for the immediate use of body building and respiration by the cell and the remaining part of it is converted into sugars and



stored away. The other five molecules of phosphoglyceraldehyde after undergoing a series of changes form Ribulose diphosphate. This cycle of changes is called " Calvin Cycle." Energy required for this process is supplied by ATP formed in the light reaction.

Experiments

1. *To show that oxygen is evolved during photosynthesis*: A few bits of a water plant namely *Hydrilla* are placed in a beaker filled with water. They are covered by a short stemmed funnel. Care is taken to see that the stem of the funnel is below the level of water and also that the cut ends of the bits are inside the stem of the funnel. A test tube filled with water is inverted over the stem of the funnel. The set up is kept in the sunlight.

After some time, bubbles of gas will be seen to be coming up from the cut ends of the plant. The gas collects in the test tube

by the displacement of water. When sufficient quantity of gas has been collected in the test tube, the test tube is removed and a red hot splinter is introduced. The splinter burns into a flame, thereby proving that the gas collected is oxygen. This experiment proves that oxygen is evolved during photosynthesis (Fig. 3.45A).

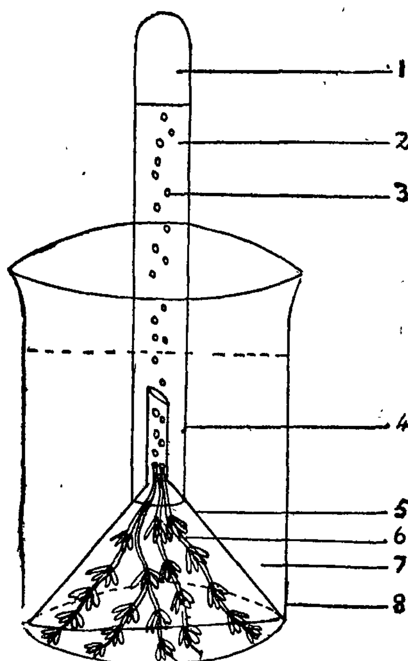


Fig. 3.45-A Experiment to show the evolution of oxygen during photo synthesis
1. Oxygen 2. Water 3. Air bubble 4. Test tube 5. Funnel 6. Water plant 7 Water 8. Beaker

2. *Experiment to show that starch is formed during photosynthesis:* A leaf is removed from a plant which is exposed to sunlight. It is dipped in boiling water for sometime to kill the tissues. Then the leaf is put in warm alcohol. The chlorophyll which is soluble in alcohol, is removed from the leaf and the leaf becomes white. The decolourised leaf is treated with iodine. It is found that the leaf turns blue, thus showing the presence of starch.

3. *Experiment to show that light is necessary for photosynthesis—Ganong's light screen experiment:* A potted plant is kept in darkness

for about 2 days to make the leaves starch free. One of the leaves of the plant is removed and tested for starch. This leaf will not turn blue, showing the absence of starch. To another leaf of the plant, a light screen is attached. A light screen consists of a metal box and a disc attached to it by a clip. A starshaped figure is cut in the disc. The plant is then placed in sunlight.

After few hours, the leaf is removed and tested for starch. It is found that only the portion of the leaf which was exposed to the light turns blue while the portion of the leaf covered by the

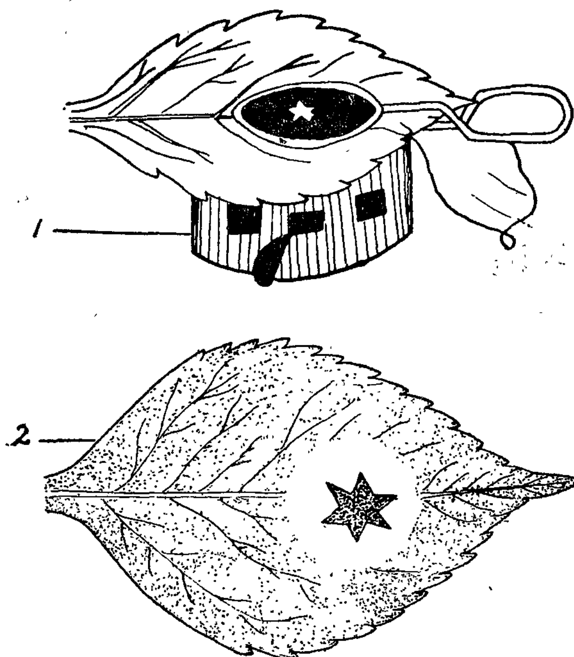


Fig. 3.46 Ganong's light screen experiment.
1. Light screen 2 Leaf after starch test

light screen and not exposed to light remains colourless. this experiment proves that light is necessary for photosynthesis (Fig 3.46).

4 *Experiment to show that CO_2 is essential for photosynthesis—Mohl's experiment* A pot plant is kept in darkness for 24 hours to

make the leaves starch free. A small quantity of caustic potash solution is taken in a wide mouthed bottle which is provided with a split cork. A leaf of the plant is introduced into the bottle through the split cork in such a way that the terminal half of the leaf is inside the bottle and the basal half, outside The bottle is kept in a position with a support. The apparatus is kept in sunlight.

After sometime the leaf is removed and tested for starch. The portion of the leaf which was outside the bottle turns blue. This is because CO_2 is available for this portion from the atmosphere. The portion of the leaf which was inside the bottle does

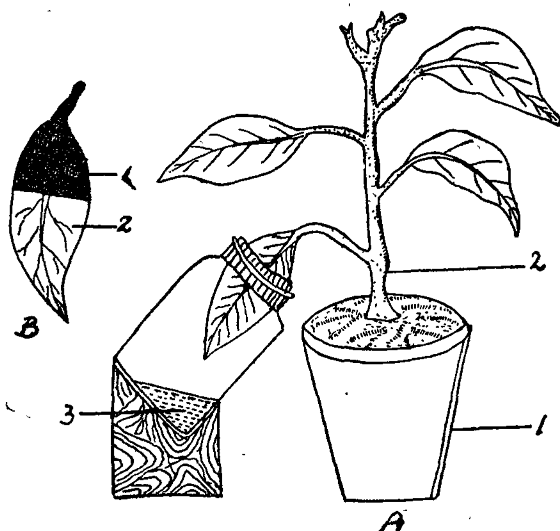


Fig. 3.47 Mohl's experiment
A—1. Pot 2. Plant 3. Caustic potash solution
B—Leaf after starch test
1. Portion of the leaf with starch 2. Portion of the leaf without starch

not turn blue. This is because caustic potash solution inside the bottle absorbs all the carbon dioxide. This experiment proves that CO_2 is essential for photosynthesis (Fig. 3.47).

5. *Experiment to show that chlorophyll is necessary for photosynthesis:* Croton leaf shows coloured patches including green Such

leaf is described as a variegated leaf. A croton plant is placed in darkness for a day or two. Then the plant is exposed to sunlight. The green portions are marked on the leaf. The leaf is then removed and tested for starch. It is seen that only the green portions of the leaf turns blue, thereby indicating the presence of starch. This experiment proves that chlorophyll is necessary for photosynthesis.

TRANSPIRATION

Plants absorb a large amount of water from the soil through the root hairs. All the water absorbed by the plant is not utilised by it. Only a very small quantity of water is retained in the plant for its life processes. The greater part of water is lost by the aerial parts of the plant in the form of water vapour. The loss of water in the form of water vapour from the aerial parts of the plant is known as Transpiration.

Transpiration may take place from any part of a plant which is exposed to the atmosphere. However, the leaves are the principal organs of transpiration.

Transpiration is of three types: stomatal, cuticular and lenticular. Most of the transpiration from leaves takes place through the stomata and this is called *Stomatal transpiration*. Some transpiration takes place from the epidermal cells of the leaf through the cuticle and this is known as *Cuticular transpiratiou.* Loss of water vapour takes place also through the small openings called lenticels present in the fruits and woody stems and this is termed *Lenticular transpiration.*

Transpiration can be demonstrated by simple experiments.

1. *Experiment to show that transpiration takes place through leaves—Bell Jar experiment:* Two well watered pot plants are taken. The mouths of the pots are covered with rubber sheets to prevent the evaporation of water from the soil. In one of the plants all the leaves are removed and vaseline is smeared over the cut surfaces. The two plants are then kept separately under bell jars. The set up is left in sunlight.

After sometime it is observed that water drops appear on the inner surface of the bell jar enclosing the plant with leaves. In the

second case where leaves have been removed there is no such accumulation of water. In the first case the formation of water droplets is due to loss of water from the aerial parts of the plant.

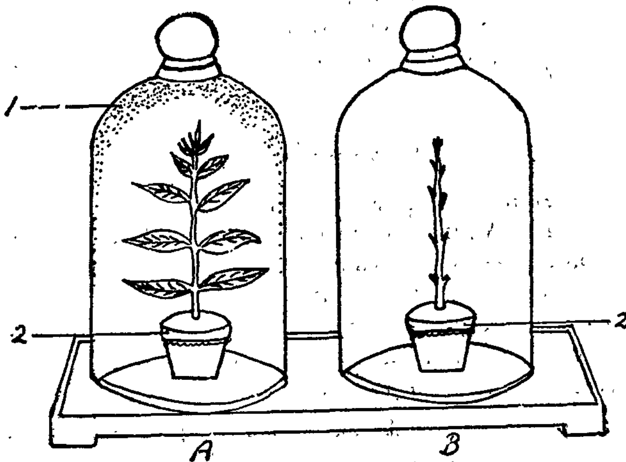


Fig. 3.48 Bell Jar experiment
A—Plant with leaves B—Plant where leaves removed
1. Water drops 2. Rubber sheet

The absence of water vapour in the second case shows that transpiration takes place through the leaves (Fig. 3.48).

2. *Experiment to measure the rate of transpiration using Ganong's Potometer:* The rate of transpiration may be measured by the use of an apparatus called Ganong's potometer.

Ganong's potometer consists of a horizontal graduated capillary tube with one end bent downwards and the other end bent upwards. The end which is bent upwards is dilated and fitted with a one holed rubber cork. A water reservoir with a stopcock is attached to the horizontal tube. The whole apparatus is mounted on a stand.

The apparatus is filled with water A small branch is cut under water and fixed to the one holed cork. The connections are made airtight. An air bubble is introduced at the end which is bent down and this end is kept immersed in a beaker of water.

As the leaves transpire, the cut end of the branch absorbs water and the air bubble moves along the graduated horizontal tube. From the distance travelled by the air bubble in a particular time, the rate of transpiration can be calculated.

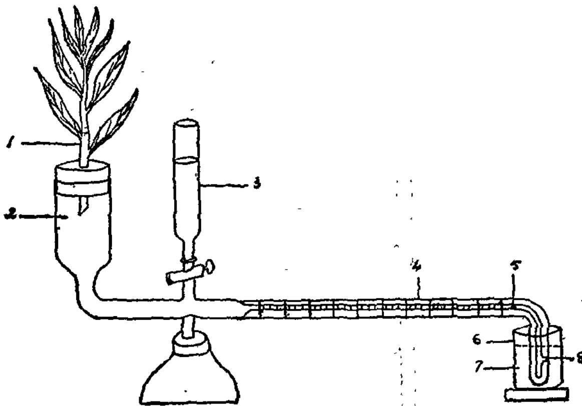


Fig. 3.49 *Ganong's potometer*

1 Cut branch 2. Water 3. Water reservoir 4 Graduated capillary tube 5. Air bubble 6 Beaker 7. Water 8. Pore

The experiment can be performed by keeping the apparatus in direct sunlight, in shade, and so on, in different environments and the rate of transpiration under different environmental conditions can be observed (Fig. 3.49).

Transpiration causes a suction force in the xylem, by means of which ascent of sap takes place. This can be proved by the following experiment.

3. *Experiment to demonstrate suction due to transpiration—Lifting power of transpiration:* The apparatus consists of a wide tube open at both ends and fitted at each end with a one holed rubber cork. To one end is attached a long narrow tube. The apparatus is filled with water and a fresh shoot is cut and inserted under water through the cork in the other end. The apparatus is made perfectly airtight. The lower end of the long narrow tube is dipped in mercury in a beaker This apparatus is fixed to a stand.

After a few hours it is seen that mercury has risen up in the tube to a considerable height. This shows that the branch loses water through leaves by transpiration. Transpiration causes a suction

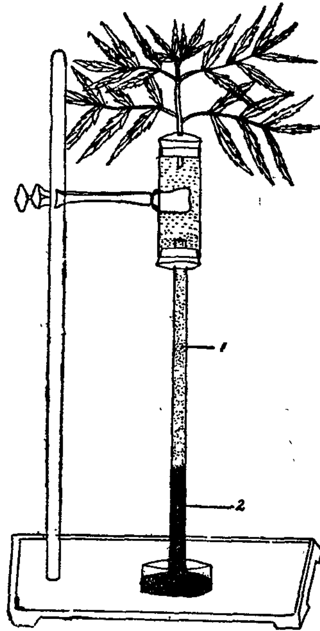


Fig. 3.50 Experiment to demonstrate the lifting power of transpiration
1. Water 2. Mercury

force and this causes the mercury to rise up in the tube and this gives a measure of the lifting power of transpiration (Fig. 3.50).

Mechanism of stomatal opening and closing

The stomata are considered as the chief organs of transpiration. Stomatal movements are brought about by changes in the volume and shape of the guard cells. The expansion and contraction of the guard cells must be due to the turgidity and flaccidity respectively. When the guard cells absorb water from the surrounding cells, they become turgid and they curve away from each other, resulting in the widening of the stomatal pore. When the guard cells lose water, they become flaccid and the stoma is closed by the straightening of the curvature of the guard cells.

Factors influencing transpiration

Transpiration is influenced by a number of factors which can be classified into external and internal factors.

External Factors

1. *Light*: Transpiration in light is much greater than in darkness. Light increases transpiration by raising the temperature of the leaves. Secondly, it causes the stomata to open widely, leading to greater transpiration. Thus light affects transpiration in two ways.

2. *Temperature*: Increase of temperature increases transpiration.

3. *Wind*: High wind increases transpiration because it instantly removes water vapour from the transpiring surfaces.

4. *Humidity*: A humid atmosphere decreases transpiration. When the atmosphere is very dry, loss of water vapour from the leaves is very great. When the atmosphere becomes moist, loss of water vapour is less.

Atmospheric pressure and available soil water also affect the rate of transpiration.

Internal factors

1. The rate of (stomatal) transpiration depends upon the number, size and distribution of stomata on the leaves.

2. The presence of thick cuticle, wax etc., reduces the rate of (cuticular) transpiration.

3. The internal structure of the leaf and water content of the mesophyll cells also affect the rate of transpiration.

Adaptations to reduce excessive transpiration

Plants growing in dry places show special adaptations for preventing excessive transpiration. Some of the adaptations are:

1. The stomata are reduced in number. They are placed in a sunken cavity and covered with protective hairs e.g. Nerium leaf.

2. Leaves are very small (eg. *Euphorbia*) or reduced to scales (eg. *Casuarina*) or modified into spines (eg. *Opuntia*)

3. Surfaces of leaves possess thick cuticle or a coating of **wax** or numerous hairs.

4. The epidermis of the leaf is many layered e.g. Neruim

5. Leaves place themselves vertically to avoid strong sunlight.

6. In grasses, the leaves role up so that the surface on which stomata chiefly occur is less exposed to air.

Significance or uses of transpiration

Some consider transpiration as of great benent to the plant while others regard it as harmful.

Advantages:

1. Transpiration helps the plant to get rid of the excess of water absorbed by the roots.

2. Transpiration helps in regulating the temperature of the plant.

3. Transpiration helps in raising water to the top of the tree by acting as a sucking force and also helps in distributing water throughout the plant.

Disadvantages:

The stomata are the organs through which not only transpiration but also exchange of gases for the vital activities of the plant like photosynthesis and respiration takes place. Hence the stomata cannot be kept closed for a long time. When they are kept open for photosynthesis and respiration, transpiration will also take place. Therefore transpiration is regarded as a necessary evil or unavoidable evil. Moreover, if the rate of transpiration is high and the supply of soil water is not sufficient, the plant may face a great shortage of water in its cells.

The loss of water from plants may also take place in the form of liquid and this process is known as *Guttation* or *Exudation.* It is commonly found in the early morning in plants like grasses, *Colocasia* etc., as water drops along the margins or apices of leaves. These water drops contain some solutes. Guttation takes place through pores called *Water stomata* or *Hydathodes* present in the leaves.

Storage

In some leaves, water and food materials are stored up. Such leaves are usually fleshy and succulent (e.g.) *Agave*, *Aloe*, *Bryophyllum*. In some plants, the leaves are modified into pitcher-like structures for storing water and humus (e.g.) *Nepenthes*, *Dischidia*. Scale leaves of bulbs also store water and food materials.

ECONOMIC IMPORTANCE OF LEAVES

Leaves are very useful to us in many ways.

1. *Food:* The leaves of *Amaranthus*. *Alteranthera*, *Sesbania grandiflora* are used by us as greens.

2. *Spices:* The leaves of *Murraya koenigii*, *Coriandrum sativum* are used to give flavour to dishes.

3. The green leaves of *Musa sapientum*, *Canna indica* are used as dining plates.

4. The leaves of *Piper betel* are useful for chewing.

5. Tea is prepared from the leaves of *Thea Sinensis* which is used as a beverage.

6. *Fibres* are extracted from the leaves of *Agave americana* and are used in various ways.

7. Tannins are extracted from the leaves of *Rhus glabra* *Rhus typhina* and *Cinnamomum typhina*. Tannins are used in Tanneries.

8. *Medicines:* Many leaves are used in allopathic and indigenous medicines.

(*a*) Allopathic medicines are prepared from the leaves of the following plants.

Atropa belladonna	Medicine for cough.
Erythroxylòn coca	Medicine for hysteria
Digitalis purpurea	Medicine for blood pressure
Eucalyptus species	Medicine for headache

(*b*) The leaves of the following plants are extensively used in the preparation of Ayurvedic and Siddha system of medicines;

(e.g.) *Abutilon indicum, Eclipta alba, Phyllanthus niruri, Solanum trilobatum etc.*

9. *Dye:* Indigo dye is extracted from the leaves of *Indigofera tinctonia.*

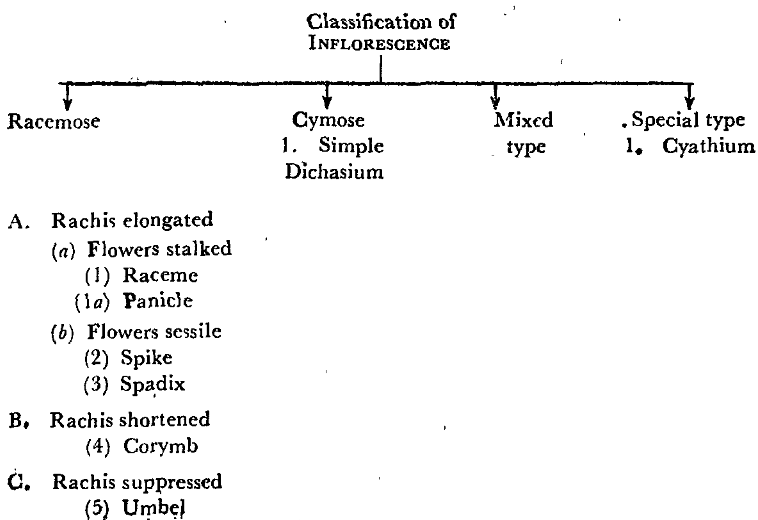
10. *Green manure:* The leaves of following plants are useful as green manure. (e.g.) *Tephrosia purpurea, Gliricidia maculata, Indigofera tinctoria, Crotolaria juncea.*

11. *Cattle Feed:* The leaves of the following plants are useful as cattle feed. (e.g.) *Cyanodon dactylifera, Panicum maximum, Pennisetum purpureum, Medicago sativa, Cenchrus ciliaris.*

Chapter IV

INFLORESCENCE

When plants gives rise to branches and leaves, it is said to be in its *Vegetative phase*. After this, the plant gives rise to flowers, ruits and seeds, which is called the *Reproductive phase*. *Reproduction* by seeds derived from flowers is known as *Sexual Reproduction* and it involves a highly complicated process in contrast to *Vegetative propagation* Each flower is a specialised part of the shoot, adapted for the purposes of reproduction. The flowers may occur singly or in clusters. Flowers borne singly are called *solitary*. The solitary flower may either be axillary replacing an axillary shoot or terminal, replacing the terminal bud. When flowers are arranged in clusters they are grouped together in branches which are quite different from vegetative branches. *The specialised branch system with a number of flowers is known as the Inflorescence.* The main axis of an inflorescence is called the *peduncle*. The individual flowers are attached to this peduncle by small stalks known as *pedicels*. The flowers without stalk are knows as *sessile*.



Classification of Inflorescence

I. Racemose type of Inflorescence

The main axis of the inflorescence grows indefinitely bearing the flowers directly or on its branches.

The main axis is indefinite or *interminate* in its growth bearing a number of lateral flowers in the axils of small leaf like structures called *bracts*. The oldest flowers are at the base or bottom of the inflorescence and the youngest towards the apex. This type of arrangement of flower is called *acropetal succession*.

When the flowers are brought to the same level by the lengthening of the lower pedicels, the order of opening of the flower is from the periphery to the centre *in Centripetal*. Racemose inflorescence may be further sub-divided according to the nature of the growth of the peduncle and presence or absence of pedicel

A. With main axis elongated

(*a*) *Flowers stalked.*

1. *Raceme:* In a Raceme, the inflorescence axis is very much elongated and a number of stalked flowers arise in the axils of bracts in an acropetal succession. The pedicels of flowers are of the same length.

(e.g.) *Crotalaria verrucosa*, *Cleome viscosa* (Fig. 4.1)

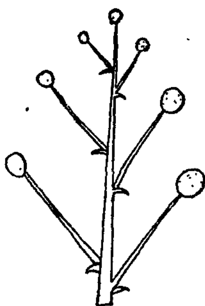


Fig. 4.1 Raceme

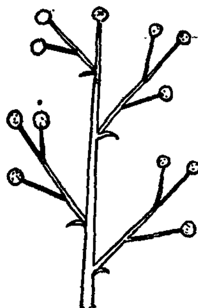


Fig. 4.2 Compound raceme

1. (*a*) *Panicle or compound raceme:* When the main axis of a raceme branches and the flowers are borne not directly on the axis but on its branches then the inflorescence is called a panicle. (e.g.) *Peltophorum furrugineum.* (Fig. 4.2)

(*b*) *Flowers sessile*

2. *Spike:* This is just like the raceme, but the flowers are sessile (e.g.) *Achyranthes aspera, Piper longum,* (Fig. 4.3)





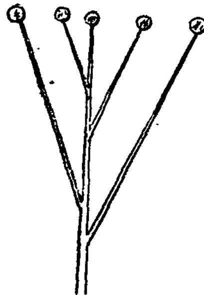
Fig. 4.3 Spike   Fig. 4.4 Spadix

3. *Spadix:* This is the variation of the spike, in which the rachis is thick and fleshy and the flowers are sessile being protected by a large bract called *spathe* (e.g.) *Colocasia antiquorum.* (Fig. 4.4)

In the fleshy axis of the spadix male flowers are arranged at its top, neutral flowers are in the middle and the female flowers are at the bottom.

B. Peduncle shortened

4. *Corymb:* Here the peduncle is not very much elongated as in a raceme. Flowers found on the lower part of the axis



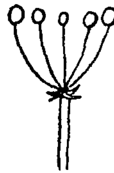


Fig. 4.5 Corymb   Fig. 4.6 Umbel

are having longer pedicels and flowers found towards the top of the axis will have shorter and shorter pedicels, so that *all the*

flowers are placed at the same level (e.g.) *Cassia auriculata, Gynandropsis pentaphylla* (Fig. 4.5)

C. Peduncle suppressed

5. *Umbel:* Here the inflorescence axis is very much shorttened than in corymb type. There are a cluster of bracts on the tip of the shortened axis. These bracts are called *involucre of bracts.* At axils of these bracts flowers having stalks of equal length arise, so that all the flowers are brought to the same level. (eg.) *Allium cepa* (Fig 4.6)

Corymb and umbel inflorescence may be compared for clarification. In corymb, the pedicels vary in length and are attached to the peduncle at various levels. In an umbel, the pedicels are of the same length attached at the tip of the shortened axis.

II. Cymose type of inflorescence

Here the growth of the main axis of the inflorescence is *limited or determinate.* It stop its growth after giving rise to a flower with a bracteole. The bracteole of this flower becomes the bract of the second set of flower which arise in its axil.

In the cymose type of inflorescence the central flowers of the inflorescence are the oldest and the basal flowers are younger which is in contrast to the racemose types. Further in cymose

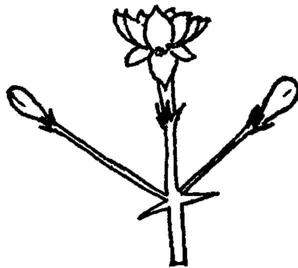


Fig. 4.7 Simple dichasium

inflorescence the opening of the flowers is from the centre to the periphery that is centrifugal whereas it is centripetal in racemose types. There are many types under cymose inflorescence.

1. *Simple Dichasium:* The main axis ends in a flower. This flower has two bracteoles and from the axil of each, a lateral flower develops. In this cluster of three flowers the central flower is the oldest and opens first, while the two lateral flowers are younger and opens later. This type is just opposite to the condition found in racemose clusters (e.g.) Jasmine (Fig. 4.7)

SPECIAL TYPES

The inflorescence could not be assigned either to racemose or cymose types and are treated as special types.

1. *Cyathium:* This is a special kind of cymose inflorescence found in the genus Euphorbia, reduced to look like a single flower

There is a cup shaped structure found by the union of the bracts with beautifully coloured nectaries found on its top. The extremely reduced flowers are arranged on a convex *receptacles.* There is a central female flower reduced to a pistil, subtended by a long *stalk.* This is surrounded by five groups of reduced male flowers arranged in the form of monochasial scorpioid cymes. Each male flower is having a short stalk, a filament and two anther-lobes arising from the base of a scaly bract. (eg.) *Euphorbia heterophylla, Poinssettia pulcherrima.*

Chapter V

THE FLOWER

The flower is a reproductive dwarf shoot consisting of an axis, bearing the essential organs like Androecium and Gynoecium with some accessory organs like Calyx and Corolla.

PARTS OF A FLOWER

The flower develops from the flower-bud. The flower consists of nodes and internodes similar to the vegetative shoot. But in flowers, the internodal portions are very much condensed. As in the shoot system, the flower has got a *floral axis.* The tip of the floral axis is known as the *thalamus, torus* or *receptacle.* The floral leaves are inserted on the floral axis similar to the leaves on the vegetative shoot. The prefoliation of the young leaves is like the aestivation of floral leaves.

Generally, a flower consists of four whorls of floral parts.

1. Calyx composed of sepals

2. Corolla consists of petals

Since these two whorls are not directly taking part in reproduction, they are called accessory organs.

3. Androecium (Microsporophylls) is made up of stamens which represent the male reproductive part of the flower.

4. Gynoecium is made up of carpels (Megasporophylls) and is the female reproductive part of the flower. Since Androecium and Gynoecium are directly taking part in reproduction, they are called essential organs.

The following is a list of technical terms useful in the general description of the flower.

I. Pedicel

1. Pedicellate—A flower with a pedicel.
2. Sessile—A flower without a pedicel.

II. Bract and Bracteole

1. Bracteate—A flower that arises in the axil of a bract or subtended by a bract.
2. Ebracteate—A flower without a bract.
3. Bracteolate—A flower with bracteoles
4. Ebracteolate—A flower without bracteoles.

III. Complete and Incomplete Flowers

1. *A complete flower* is one in which all the four whorls of floral parts are present.
2. *Incomplete flower* is one in which anyone or more of the floral parts are absent.

   (a) *Achlamydeous:* The calyx corolla are absent in the flower

   (b) *Apetalous:* The corolla alone is absent in the flower

IV. Sex distribution

1. *Bisexual, hermaphrodite, perfect or monoclinous flower:*

Flowers in which both androecium and gynoecium are present.

2. *Unisexual, imperfect or diclinous flower:* Flowers in which only one set of essential organs namely either the gynoecium or the androecium is present and not both.

   (a) *male or staminate flower:* Only androecium is present.

   (b) *female or pistillate flower:* Only gynoecium is present

   (c) *Monoecious:* Flowers unisexual and the male and the female flowers are present in the same plant. (e.g.) *Cocos nucifera*

   (d) *Dioecious* Flowers unisexual and the male and the female flowers are present in two different plants (e.g.) *Caricha papaya, Borassus flabellifer.*

   (e) *Polygamous:* Bisexual and unisexual flowers are present in the same plant (e.g.) *Mangifera indica*

V. Symmetry of the Flower

(A) In arrangement

1. *Acyclic:* The floral parts are spirallv arranged on an elongated thalamus. (e.g.) *Magnolia*

2. *Cyclic:* Floral members of different whorls are arranged alternate to each other. For example corolla is alternately arranged to calyx. (e.g.) *Calotropis.*

3. *Hemicyclic:* Amongst the four whorls of floral leaves, calyx and corolla are arranged in a cyclic manner and androecium and gynoecium arranged in an acyclic manner (e.g.) *Anona squomosa.*

(B) In numbers

1. *Anisomery:* With unequal number of floral parts in each whorl of flower.

2. *Isomery:* With equal number of floral parts in each of the whorls. This may further be divided into two types.

   (*a*) *trimerous flower:* Floral parts in each whorl are in threes or multiples of it. eg. Monocotyledonous flower

   (*b*) *tetramerous or pentamerous flower:* Floral parts in fours or fives or in the multiples (eg.) Dicotyledonous flowers.

(C) Floral symmetry in form

In some flowers, the individual floral parts of a whorl may be similar in structure and form whereas in some others, they may be different in structure and form. Accordingly the flowers may be divided into two major groups.

1. Symmetrical flowers.

2. Asymmetrical flowers.

1. *Symmetrical flowers:* The flower with a symmetry is called a symmetrical or regular flower This is divided into two types (Fig. 5.1)

   (*a*) *Actinomorphic or radial symmetry:* Here the floral members are proportionately arranged on the thalamus and

the individual floral parts of a whorl are similar in structure and form so that the flower may be divided into two equal halves through any vertical plane passing through the axis. (e.g.) *Thespesia populnea*

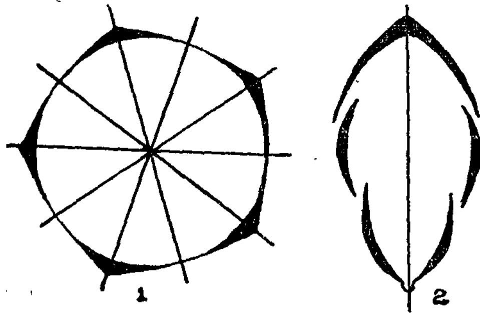


Fig. 5.1 Symmetry
1 Radial symmetry 2. Bilateral symmetry

(*b*) *zygomorphic or bilateral symmetry:* There are some flowers in which the individual parts of the whorl differ in form and structure, so that it can be divided into two equal halves only if it is cut in only one vertical plane of the axis (e.g.) *Crotalaria verrucosa*

2. *Asymmetrical or irregular flowers:* If the individual floral parts of the whorls are quite different in structure and form where the flower cannot be divided into two equal halves if it is cut along any vertical plane of the axis. (e.g.) *Canna indica.*

Bracts and bracteoles

Bracts are special leaves (hypsophylls) at whose axils, the flowers are borne. They serve for the protection of flower buds in the young stage. There are also small structures in between flower and bract known as bracteoles. There are many variations in the structure, colour and function of the bracts and bracteoles.

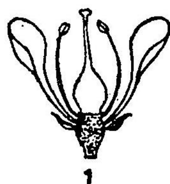
Thalamus

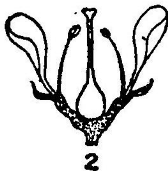
The thalamus is that part of the flower stalks to which the floral parts are attached. It has four nodes on which four whorls of floral parts are attached. The internodal parts of the thalamus are very much condensed.

There is great variation in the thalamus. In a few plants it may be elongated (*Michelia Champaka*), expanded (*Nelumbium speciosum*); or may be elongated between the whorls of floral parts.

When the thalamus presents no modification, it is just a small convex protuberance above the calyx, bearing, at its summit the pistil. So the level of the pistil is above calyx, corolla and androecium. The ovary is then described as *superior.* Since the other parts of the flower are below the level of the ovary, the flower is described as *hypogynous.* (e.g.) *Thespesia populnea.* (Fig.5.2)

In some flowers the thalamus becomes hollowed out into a cupshaped structure. The pistil is situated in the centre of the cup. The other floral parts are arranged on the edge of the cupshaped





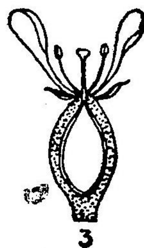


Fig. 5.2 Hypogynous flower

Fig. 5.3 Perigynous flower

Fig. 5.4 Epigynous flower

thalamus so that they are found around the pistil and so the flower is said to be *perigynous.* The other floral parts are elevated due to the growth of the thalamus which is below the level of the ovary; so the position can be described as superior. (e.g.) *Ceasalpinia pulcherrima, Delonix regia.* (Fig. 5.3.)

In *Psidium guajava, Cephalandra indica,* the thalamus gets completely hollowed out and fuses with that of the ovary wall, so that the position of the calyx, corolla, and androecium are brought above the ovary so that the flower is described as *epigynous* and the ovary is said to be *inferior* (Fig. 5.4)

Perianth

Perianth is a collective term for the calyx and corolla. When the components of calyx and corolla are similar in size, form, colouration, they are called *tepals* (e.g.) *Polyanthes tuberosus.*

If the tepals are coloured, they are said to be *petaloid* as in *Gloriosa superba*. If the colouration is dull and sepal like, they are termed *sepaloid* as in *Cocos nucifera*. If the tepals are united they are called *gamophyllous* (*Iris*) and if they are free, they are said to be *Polyphyllous* (*Allium cepa*)

Descriptive terms of a flower

1. *Chlamydeous*	—with a perianth
2. *Achlamydeous*	—without a perianth
3. *Monochlamydeous*	—with only one whorl of perianth
4. *Dichlamydeous*	—with two whorls of perianth
5. *Polysepalous*	—sepals free
6. *Gamosepalous*	—sepals united
7. *Polypetalous*	—petals free
8. *Gamopetalous*	—petals united

Aestivation

Arrangement of the perianth parts in the bud is called aestivation (Fig. 5.5)

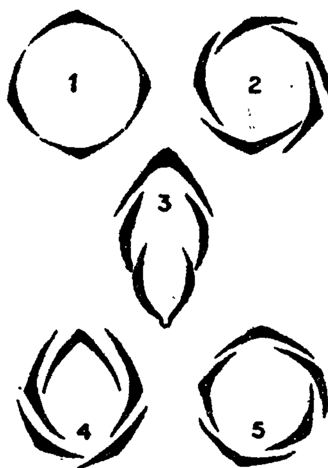


Fig. 5.5 Aestivation

1. Valvate 2. Twisted 3. Descendingly imbricate 4. Ascendingly imbricate 5. Quincuncial

1. *Valvate:* Margins of segments just touching one another, but not overlapping. (e.g.) *Anona squomosa.*

2. *Twisted:* When overlapping is regular in one direction so that one margin overlaps the next member on one side while its other margin is being overlapped by its adjacent member it is described as twisted. (e.g.) corolla of *Nerium odorum.*

3. *Imbricate:* The margin of perianth lobes overlap one another in an irregular manner. One lobe is internal being overlapped on both the margins and one lobe is external.

(*a*) *descendingly imbricate:* Here there is a large posterior petal which overlaps the two lateral wing petals which in turn overlap the united keel petals. This is characteristic of *Papilionaceous corolla.* (e.g.) *Crotaleria verrucosa.*

(*b*) *Ascendingly imbricate:* Here the anterior petal overlaps the other petals. (e.g.) corolla of *Ceaselpinia pulcherrima.*

4. *Quincuncial*: Two perianth lobes completely overlap others, while two others are completely being overlapped by others. Among the two edges of the fifth perianth one edge overlaps the adjacent while the other edge is being overlapped by the adjacent perianth.

Duration of the perianth

1. *Caducous*—falls away as the bud opens.
2. *Deciduous*—falls away after fertilization.
3. *Persistent* if found even in fruit.

Calyx

This is the outermost whorl of the flower and consists of sepals. They are usually green and leaf like in the bud stage, sepals protect the other floral parts.

Modifications

Sometimes the sepals are modified to do certain other functions

1. *Petaloid*—Coloured and petal like as in *Petrea volubilis*

2. *Pappus*—sepals are modified into hairy, scaly or feathery structures useful for dispersal. (e.g.) Compositae family.

Corolla

Corolla is the second whorl of floral leaves composed of petals. Normally they are larger than the calyx and protect the essential organs. They are usually brightly coloured and sometimes scented so as to attract insects for pollination.

When the petals of the corolla are all of the same size and shape and are arranged in a symmetrical manner, the corolla is *regular* When the petals vary in size and shape and are not symmetrically arranged the corolla is *irregular* When the lower part of the petal is narrow, it is called *claw* and its upper broad portion is called *limb*

Forms of Corolla

Depending upon the size, shape, structure and union of the petals, four important corolla types are recognised and under each type there are many varieties.

I. Polypetalous regular corolla (Fig. 5.6)

1. *Cruciform.* Four free clawed petals are arranged in the form of a cross as in the Cruciferae family.



Fig 5.6 Polypetalous regular corolla
1 Cruciform 2 Caryophyllaceous 3 Rosaceous

2. *Caryophyllaceous:* This is formed by five free clawed petals with limbs at right angles to the claws as in the Caryophyllaceae family (e.g.) *Dianthus.*

3. *Rosaceous:* Corolla consists of five spreading petals which are not clawed. (e.g.) Rose.

II. Polypetalous irregular corolla (Fig. 5.7.)

4. *Papilionaceous:* There are five petals resembling a butterfly. The posterior petal is large and outermost and is called the

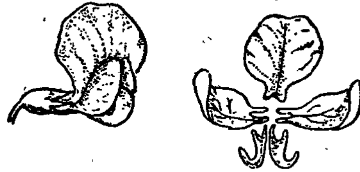


Fig. 5.7 Polypetalous irregular corolla
Papilionaceous

standard petal. In addition there are two lateral *wing petals* and two anterior united *keel petals.* (e.g.) Papilionaceae family.

III. Gamopetalous regular corolla (Fig. 5.8)

1. *Tubular:* The corolla tube is nearly cylindrical throughout and the limbs are not spreading. (e.g.) Tube florets of Compositae family.

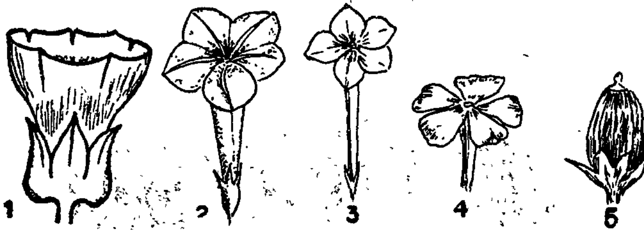


Fig. 5.8 Gamopetalous regular corolla
1. Companulate 2. Infundibuliform 3. Hypocraterjform
4. Rotate 5. Urceolate

2. *Companulate or bell shaped:* The corolla is rounded at the base and spreading above like a bell as in *Physalis minima.*

3. *Infundibuliform or funnel shaped:* The corolla resembles an inverted cone like a funnel as in *Datura.*

4. *Hypocrateriform or salver shaped:* The corolla tube is long and narrow, with a limb placed at right angles to it as seen in *Vinca rosea.*

5. *Rotate or wheel shaped:* The corolla tube is shorter and the limbs are seen at right angles to it as in *Solanum melongena.*

6. *Urceolate or urn shaped:* Corolla tube is swollen in the middle and tapering at both base and apex as in *Bryophyllum calcinum.*

IV. Gamopetalous irregular corolla (Fig. 5.9)

7. *Ligulate or strap shaped:* The fine petals are united to form a short tube at the base, which splits on one side and becomes

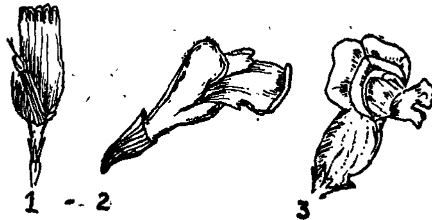


Fig. 5.9 Gamopetalous irregular corolla
1. Ligulate 2. Bilabiate 3. Personate

flattened like a strap above as seen in the ray florets of the Compositae family.

8. *Bilabiate or two lipped*: There are five irregular petals, united in such a way that the limb is divided into an upper posterior part formed by the union of two petals, and an unequal lower part formed by the union of three petals. (e.g.) *Leucas aspera.*

9. *Personate or masked:* It resembles the bilabiate corolla but the two lips are placed so close together that the mouth is closed (e.g.) *Antirrhinum majus.*

ANDROECIUM

Androecium constitutes the third set of floral organs and the first set of essential organs. Androecium is composed of *stamens* or microsporophylls. Each stamen consists of a basal stalk, the *filament,* bearing at its top *antherlobes* (microsporangia), connected by means of a special tissue called *connective.* Antherlobes contain *microspores* or *pollen grains.*

Filament (Fig. 5.10)

In rare cases, the stamens may be without a filament or *sessile* as in *Arum maculatum.* If the stamen is not having a fertile anther, it is *sterile* and is called a *staminode.* (e.g.) *Cassia auriculata.*

In *Canna indica* the filaments are modified into a flat expanded coloured structures and are said to be *petaloid*. Generally, the filament is *simple* without any branches. But in *Ricinus communis*, the filament is much branched. Filaments sometimes bear appendages and are called *staminal corona* as in *Calotropis*.

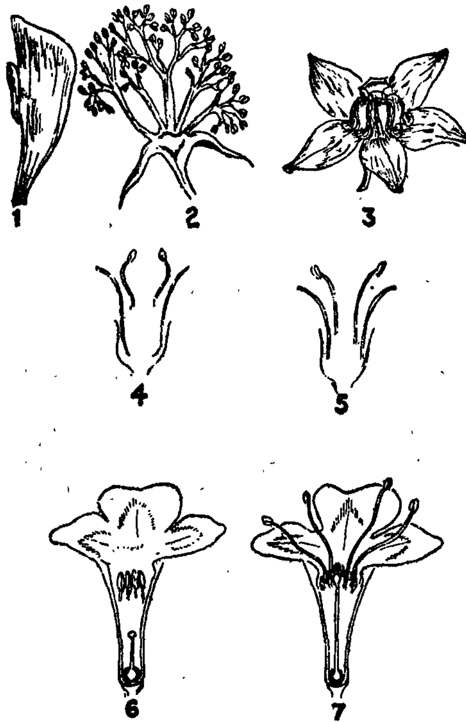


Fig. 5.10 Stamens
1. Petaloid stamen 2. Branched stamen 3. Staminal corona
4. Incurved 5. Recurved 6. Inserted 7. Exserted

The filament may be either erect or curved. When it is curved inwards, it is said to be *incurved*, and when curved outwards, it is described as *recurved*.

In some flowers the filaments are shorter than the corolla tube so that the stamens could not be seen outside the corolla. Such stamens are said to be *inserted or included*. When the filaments are long, so that the stamens project out of the corolla tube, they are called *exerted or protruding*.

The anther

The anther usually consists of two longitudinal lobes placed on either side of the upper part of the filament which forms the connective. The connective is attached to the back of the anther. The opposite side of the anther is the *face*, and it always presents a grooved appearance. If the faces of the anthers are turned towards the centre of the flower, the anthers are said to be *introrse* (e.g.) *Nymphaea stellata*. But when the face of the anther is turned outwards, the anther is termed *extrorse* (e.g.) *Iris, Colchicum autumnale.*

Rarely the anther becomes unilocular or one chambered and is called *Monothecous* as in Malvaceae family.

Attachment of the anther to the filament

The mode of attachment of the anther to the filament varies (Fig. 5.11).

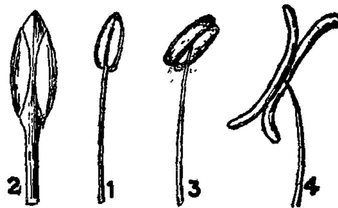


Fig. 5.11 Attachment of the anther
1. Basi fixed 2. Adnate 3. Dorsi fixed 4. **Versatile**

1. *Basifixed*: The tip of the filament is attached to the base of the anther lobe (e.g.) Mustard.

2. *Adnate:* The filament or its continuation, the connective is attached to the whole length of the back of the anther as in *Magnolia champaka.*

3. *Dorsifixed:* The filament is firmly fixed to the same position on the back of the anther as in *Sesbania grandiflora,*

4. *Versatile:* Filament is attached merely at a point about the middle of the anther lobe so that the anther can swing freely (e.g.) Grasses,

Dehiscence of the anthers

When the anthers become mature, they burst discharging the pollen grains. This is known as *dehiscence* and the time when this takes place is called *anthesis*. Dehiscence may be of different types (Fig. 5.12)

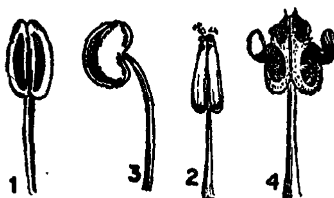


Fig 5.12 Dehiscence of the anther
1 Longitudinal 2 Apical 3. Transverse 4. Valvular

1. *Longitudinal* Anther lobes burst along the longitudinal slits to liberate the pollen grains (e.g.) *Datura.*

2. *Apical or porous* Each lobe of the anther opes at the tip by means of a small opening or pore as in *Cassia auriculata.*

3. *Valvular* At the top of each lobe of the anther, the wall opens like a trap door or shutter, through which pollen grains are released as in *Berberis, Laurus*

4. *Transverse* Antherlobe splits open transversely to release the pollen grains as in the members of Malvaceae family.

The Connective

Generally, the connective is inconspicuous so that the two lobes of the anther are closed to each other But sometimes the connective is conspicuous and broad.

Arrangement of stamens

The stamens may be arranged in whorls or arranged spirally as in *Annona*. In *Eucalyptus* there are many stamens arranged in many concentric whorls. When the stamens are arranged in two whorls, they may be *diplostemonous* in the outer whorl alternates with petals and the inner whorl is opposite to petals; or *obdiplostemonous* where the outer whorl is antipetalous and the inner whorl is alternating with the petals,

On the insertion of the stamens, they may be *free* or inserted on the petals and are said to be *epipetalous* as in gamopetalous corollas.

Union of stamens

Union of similar parts is known as *cohesion* and union of dis similar parts is known as *adhesion* as union between petal and stamen. Cohesion involving filaments is called *adelphy* and cohesion involving anthers is called *syngeny*. (Fig. 5.13)



Fig. 5.13 Union of stamens
1. Monadelphous 2. Diadelphous 3. Polyadelphous 4. Syngenesious

1. *Monadelphous:* The filaments of all the stamens are united together to form a tubular structure enclosing the pistil. (e.g.) *Thespesia populnea.*

2. *Diadelphous:* The filaments are united into two bundles. In *Clitoria* there are ten stamens; the filaments of nine stamens are united into one bundle and the tenth stamen remains free as the second bundle.

3. *Polyadelphous:* There are numerous stamens and they are united into a number of bundles (e.g.) *Bombax malabaricum.*

4. *Syngenesious:* Here the filaments are all free, but the anthers are all united so as to form a tube. (e.g.) *Helianthus annuus.*

Length of the stamens

All the stamens of the flowers may be of the same length, or of different lengths. In *Leucas aspera* there are four stamens, out of which two are longer of equal length and two are shorter of same length, they are said to be *didynamous*. In mustard and radish there are six stamens out of which four are longer of the

same length and the other two are shorter of the same size and are said to be *tetra dynamous.* (Fig. 5.14)

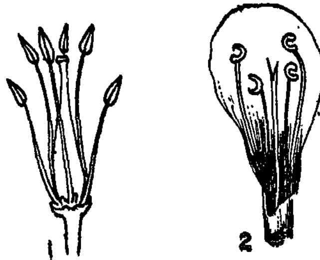


Fig. 5.14 Length of the stamens
1. Tetradynamous 2. Didynamous

THE GYNOECIUM

The gynoecium or pistil constitutes the fourth set of floral leaves and the second set of essential organs. It consists of a basal enlarged portion called the *ovary* with *ovules* attached to the *placenta.* Above the ovary, the pistil is protruded into a long or short *style* which ends in a sticky *stigma.*

The pistil is made up of one or more *carpels* or *megasporophylls.* When there is a single carpel the pistil is called *simple* or *mono-carpellary.* If the pistil is made up of more than one carpel, it is said to be *compound* or *poly carpellary.* Monocotyledonous flowers are characterised by *tricarpellary pistils* whereas dicotyledonous flowers are characterised by *tetra carpellary* or *pentacarpellary pistils.*

In a polycarpellary pistil, if the carpels are free from one another, it is termed *apocarpous* (e.g.) Annonaceae, Magnolaceae. If the carpels are united the pistil is called *syncarpous.* The syn-carpous pistil may be formed in either of two ways:

1. It may be formed by the union of *closed carpels* so that in the ovary, there are as many locules (cells) as the number of carpels as in *Gossypium*, *Agave* and *Canna.*

2. It may be formed by the union of *open carpels,* the car-pellary leaves fusing by their continuous margins, where there will be only a single locule as in *Passiflora, Cucurbita maxima,*

When the ovary has got a single locule or cell, it is described as *unilocular.* When there are more than one cell they are described as *multilocular* (many cells).

The Ovary

Ovary is the most important part of the pistil as it contains the ovules which develop into seeds after fertilization. A pistil without a functional ovary is sterile. The foliar origin of the carpel is clear form as in *Pisum sativum.* A leaflike carpel or megasporophyll is folded about its mid rib and forms a chamber by the fusion of the margins. There is a special tissue called *placenta* along the margin and the marginal line along which the carpel fuses is called the *ventral suture* and the middle is called the *dorsal suture.* Ovules develop from this placental tissue and remain within the ovary chamber.

Placentation

The manner in which the placentas are distributed inside the ovary wall is called *placentation* which differs widely in different plants (Fig. 5.15).

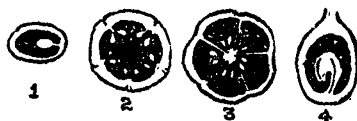


Fig. 5.15 Placentation
1. Marginal 2. Parietal 3. Axile 4. Basal

1. *Marginal placentation:* In the simple monocarpellary unilocular pistil, there is only a single placenta formed by the fused edges of the megasporophyll and situated in the vertical suture and the ovules are attached on this (e.g.) *Crotalaria labernifolia.*

2. *Parietal Placentation:* In syncarpous ovaries formed by the union of open carpels, the placentas are found along the inner wall of the ovary which is unilocular. There are as many placentas as the number of carpels (e.g.) *Argemone mexicana.*

3. *Axile placentation:* In syncarpous pistil formed by the union of closed carpels, the placentas are found at the inner angles of the cells. The number of placentas is the same as the

number of carpels forming the ovary. (e.g.) *Thespesia populnea*, *Canna indica.*

4. ***Basal placentation:*** There is only one ovule attached to the base of the unilocular ovary. (e.g.) Compositae family.

The Style

The style is the prolongation of the tip of the carpellary leaf beyond ovary. Usually it arises from the summit or top of the ovary and is called *apical.* Sometimes it is displaced towards one side of the ovary and is known as *ex-centric* or *lateral.* In the members of the family *Labiatae,* the pistil is syncarpous and the carpels are fused only at the base. The lateral styles are united together, so that the style is seen starting right from the base of the ovary and coming out between the lobes of the ovary. Such a style is said to be *gynobasic.* The style may be *simple* or branched

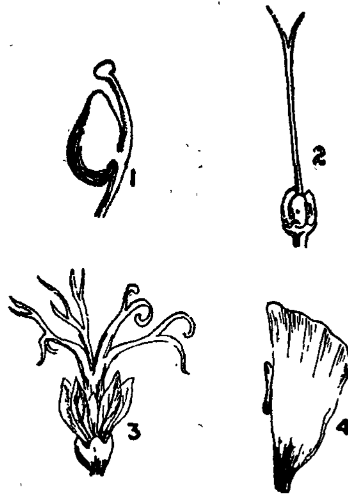


Fig. 5.16 Style
1. Lateral 2. Gynobasic 3. Branched 4. Petaloid

as in *Euphorbia.* It may be flattened and coloured as in *Canna indica* and described as petaloid. (Fig. 5.16)

The Stigma

Usually the stigma is attached to the ovary by the style. But sometimes the style is absent as in poppy. Such a stigma which is found directly on the top of the ovary is termed *sessile*. The stigma may be *simple* as in *Thespesia* or *branched* the number of branches may be equal to the number of carpels as in *Sida* (Fig. 5.17).

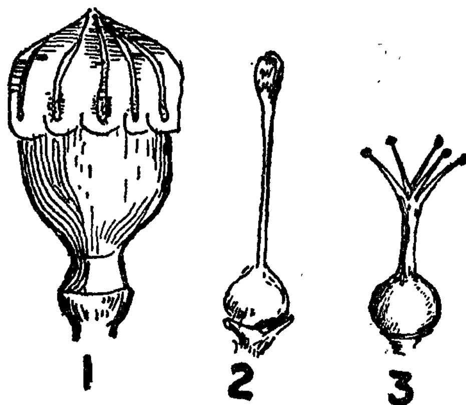


Fig. 5.17 Stigma
1. Sessile 2. Single 3. Branched

EMBRYOLOGY

Anther or Microsporangium

A typical anther consists of four elongated microsporangia. It has a column of sterile tissue called the *connective*, on either side of which is an anther lobe. When young, each anther lobe has two microsporangia. Externally, the partitions between the microsporangia can be seen as deep longitudinal grooves. Due to the breakdown of the partition between them, the two sporangia in a lobe become joined when the anther matures.

A cross section of a very young anther shows a mass of homogenous meristematic cells surrounded by the epidermis.

Development of anther

During its development the anther becomes slightly four lobed. In each lobe, rows of hypodermal cells become more prominent

by their longer size, slight radial elongation and more conspicuous nuclei. These cells form the archesporium. The extent of the

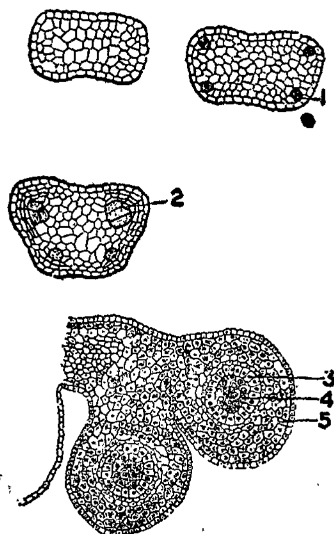


Fig. 5.18 Development of anther
1. Archesporium 2. Primary sporogensis cell 3. Tapetum
4. Spore mother cell 5. Parietal layer

archesporial issue vary considerably both breadthwise and lengthwise.

The archesporial cells divide periclinally to form a *primary parietal layer* toward the outside and a *Primary sporogenous* layer toward the inside. The cells of the primary parietal layer divide by periclinal and anticlinal walls to give rise to series of concentric layers usually three to five composing the wall of the anther. The primary sporogenous cells either function directly as the *spore mother cells* or divide further to form a large number of mother cells. (Fig. 5.18)

Anther wall

The young antherwall comprises an epidermis followed on the inside, by a layer of *endothecium,* 2 or 3 middle layers and a single layered *tapetum*. They undergo the following changes as the anther matures. (Fig. 5.19)

1. *Epidermis*: This protects the tissue inside it. The cells repeatedly divide anticlinally to cope up with the enlarging inner tissues. It is rarely seen in mature anthers.

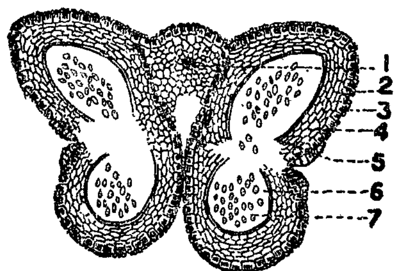


Fig. 5.19 T.S. of mature anther
1. Connective 2. Epidermis 3. Endothecium 4. Middle layer
5. Tapetum 6. Microsporangium 7. Microspore

2. *Endothecium:* This attains its maximum development when the pollengrains are to be liberated. In many plants fibrous bands of callose develop from the inner tangential walls, while the outer tangential walls remain thin.

3. *Middle layers:* The cells are shortlived and crushed by early meiosis in the pollen mother cells.

4. *Tapetum*: This is the innermost wall layer surrounding the sporogenous tissue. This is of considerable physiological significance, for all the food materials entering into the sporogenous cells must pass through this. It is composed of a single layer of cells with dense cytoplasm and prominent nuclei. Based on its behaviour, the tapetum may be amoeboid or glandular.

5. *Sporogenous tissue:* The sporogenous cells may directly function as *microspore mother cells* or may divide a few tissues. Each microspore mother cell produces four haploid *microspores or pollengrains* by Meiosis.

Dehiscence: The anther now becomes a dry structure, the partition walls between the sporangia are usually destroyed and the pollengrains are liberated by dehiscence of the anther.

Pollengrains: Each pollengrain is a minute structure. It is unicellular and uninucleate. The shape may be round, oval,

pyramidal or polyhedral. There are two protective coats. The inner one is a delicate cellulose layer called *intine* and the outer one tough, cutinised layer called *exine*. The exine is often sculptured or provided with spines, warts etc. There are thinner circular spots in the exine called *germpores*.

Structure of the Mature ovule

The ovule consists of a small stalk called *funicle* by means of which it is attached to the placentum. The junction between the funicle and ovule proper is known as *hilum*. Each ovule is surrounded by one or two integuments. The integuments do not close at the apex but leave a small opening called *micropyle*. Enclosed by the integuments, there is a special kind of nutritive tissue called the *nucellus*. The base of the nucellus opposite to the micropyle is called the *chalaza*. Near the micropylar end there is a large cell embedded inside the nucellus called the *embryosac*. It is the most important part of the ovule. (Fig. 5.20)

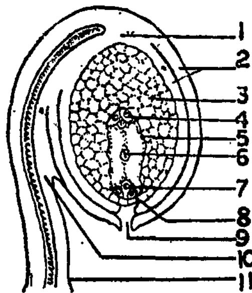


Fig. 5.20 Structure of the mature ovule
1. Chalaza 2. Integuments 3. Nucellus 4. Antipodals 5. Embryosac 6. Secondary nucleus 7. Egg 8. Synergid 9. Micropyle 10. Hilum 11. Funicle

The mature embryosac contains seven nuclei of which three remain at the micropylar end, one at the centre and the other three at the chalazal end. The three nuclei at the micropylar end form the egg apparatus. One nucleus at the middle is the *egg or* female gamete and the other two are the synergids. The three nuclei at the chalazal end constitute the antipodals and the nuclei at the centre of the embryosac is called the *secondary nucleus*.

Pollen grain

A mature pollen grain is oval or round with two wall layers. The outer thick wall is called *exine* and inner thin wall *intine*. The pollen grain contains a single nucleus, dense cytoplasm and stored food materials.

Germination of pollen

The pollen grains are brought to the stigma during pollination and further development takes place in the stigma which is known as the germination of pollen. The stigma secretes a sugary fluid. The pollen grain absorbs the sugary fluid and swells up. The exine breaks open and the intine comes out in the form of a long-tube called the *pollen tube*. The pollen tube then makes its way through the style and down the wall of the ovary. At this stage there are two nuclei at the tip of the pollen tube; the lower one is called the *tube nucleus* and the upper is called the *generative* nucleus. The generative nucleus divides into two male gametes which are at the tip of the pollen tube. As the pollen tube reaches the micropyle, the top of the pollen tube breaks and the two male gametes enter the embryosac along with the tube nucleus which soon degenerates.

Fertilization

One of the male gametes fuses with the female gamete *egg* which is known as fertilization: The fertilised egg is called *zygote*. Zygote divides a number of times to give rise to the embryo. The second male gamete fuses with the secondary nucleus forming the *primary endosperm nucleus* which develops into an endosperm. This fusion is said to be *double fertilization*.

Post fertilization changes: Soon after fertilization, the petals, the stamens, the style and the stigma wither and fall off. The calyx may persist in some cases like Brinjal. The ovary becomes bigger, slowly changes its colour and contents and becomes the fruit. The ovules become seeds. The two integuments of the ovule becomes the seed coats. The outer is called the *testa* and the inner *tegmen*. Embryo consists of the rudiments of the root (radicle), the rudiments of the shoot (plumule) and one or two cotyledons. The synergids antipodals, and nucellus disappear.

Embryo

The zygote has a period of dormancy which varies with different species.

The first division of the zygote is transverse in the majority of the angiosperms. This results in a small apical cell (Ca) toward the interior of the embryosac and a large cell (Cb) toward the micropyle. This is referred to as the 2 celled stage of the embryo.

Proembryo

From the 2-celled stage, until the initiation of cotyledons, the embryo is called *proembryo.*

POLLINATION

Sexual reproduction involves the union of male and female gametes. The male gametes are developed from the pollen grains (Microspores) and the female gamete is from the embryosac of the ovule protected inside the ovary. So the next biological phenomenon is pollination which means the transference of pollen from the anther to the stigma. Pollination is a pre-requisite to fertilisation.

Classification

Status of flowers with regard to pollination.

I. Cleistogamy: Flowers do not open and are internally self-pollinated and self-fertilised.

II. Chasmogamy: Flowers are pollinated in the open condition. This may be divided into two groups.

1. *Autogamy or self pollination:* The pollen of a flower may get deposited on the stigma of the same flower. This is possible only in bisexual flowers.

2. *Allogamy or cross-pollination:* Pollen of one flower may be deposited on the stigma of another flower of the same kind. There are three kinds.

Chasmogamy

1. *Autogamy or self-pollination:* This is possible only in bisexual flowers. It is only effective if the species is self fertile. (e.g.) *Trifolium arvense.* If it is self sterile as in *Trifolium pratense* self pollination is ineffective and cross-pollination must occur. There are two methods of Autogamy.

A. Direct autogamy: Pollen deposited directly from the anthers on to the receptive stigma.

B. Indirect autogamy: Pollen has to be conveyed to the stigma by an external agent.

Autogamy is simple and direct which involves only the internal arrangements in the flowers itself. and is not dependent upon any agents. It occurs secondarily as a concomitant of allogamy that ensures self-pollination if the biologically preferable cross-pollination should fail.

Allogamy or cross pollination: In nature, cross-pollination is more prevalent than self-pollination. Nature abhors self-pollination and favours only cross-pollination. The seeds produced as a result of cross-pollination are bigger, more numerous and germinate into better plants than the seeds produced by self-pollination. When cross-pollination takes place, the characters of the two parents are combined and this leads to the re-combination of new varieties of plants. Frequent self-pollination results in the gradual deterioration of the plants.

Contrivances for ensuring cross-pollination

1. *Dicliny or unisexuality:* Only in bisexual flowers there is a possibility for self-pollination. But in unisexual flowers, self-pollination is rendered impossible.

2. *Dichogamy or ripening of sexes at different times:*
In the bisexual flowers, where the anthers and stigma mature at the same time, self-pollination is possible. If they ripen at different times, self-pollination will be impossible. In some flowers like *Helianthus*, *Hibiscus*, and *Leucas*, the anthers ripen before the stigma, a condition known as *protandry*. In plants like cholam, *Ficus* and *Mirabilis jalaba* the stigma ripens before the anthers of the same flowers and this is termed as *protogyny*.

3. *Self-sterility*: In *Passiflora* and *Abutilon indicum* the pollen has no effect on the stigma of the same flower, only when it falls on the stigma of another flower, pollination is effected and by this self-pollination is prevented.

4. *Pollen pre-potency:* The pollen from other flowers is more effective and grows more readily when deposited on the stigma of a flower than the pollen from the same flower. (e.g.) *Leguminosae flowers*.

5. *Herkogamy:* In many bisexual flowers, self-pollination is impossible because of the peculiar position of the anthers and the stigma. The anthers may be placed above the stigma, being sticky and receptive only on its lower side as in *Vinca rosea*. Sometimes the stigma may project far beyond the position of anthers as in *Gloriosa superba*.

6. *Heterostyly:* In *Oxalis*, *Oldenlandia* and *Primula chinensis* there are two types of flowers in the same plant. In the first type the pistil is short and the stamens are situated above the stigma. In the second type the stamens are short and occupy the position of stigma of the first flower and stigma of this flower is tall and occupy the level of stamens of the first flower. Pollination occurs between the stamens and stigma of the same height.

Agents of cross-pollination

During cross-pollination, pollen from one flower should be transferred to the stigma of another flower by some external forces These are called the agents of pollination.

They are

(I) Water (Hydrophily)

(II) Wind (Anemophily)

(III) Animals (Zoophily)

I. Hydrophily or pollination by water

This occurs only in a few water plants which may occur either at the water level or below the water level. *Vallisneria spiralis* is a dioecious and submerged water plant. The female flowers are solitary and are provided with stalks, which brings them to the surface of the water. Each female flower has an inferior ovary and three long stigmas. The male flowers are produced in large numbers. They are released below the water and open on the surface. Their three perianth lobes open widely and are slightly recurved so that they rest on the surface of the water. The two anthers are held vertically. The pollen from both anthers clings together into one sticky mass.

The female flowers are not detached but are raised to the water surface on long spiral stalks. There they open, but as they are waxy, they are not wetted and cause a slight depression in the surface film of water. As the male flowers float about, a number of male flowers slide into the depressions around the female flowers, where they tend to tip over, bringing the pollen into contact with the stigmas. If a wave submerges the female flower, the surrounding male flowers are closely confined in a little bubble of air, thus assisting in pollination.

II. Anemophily or pollination by the wind

Wind pollinated flowers may show certain characteristic features.

1. Plants which are situated in wind exposed region are more wind pollinated than those which are confined to sheltered places.

2. The flowers may be pendulous as in *Quercus* and the inflorescence may be pendulous as in *Rumex*.

3. The flowers are produced after leaf-fall, so that the pollen may be carried without interference by the leaves as in *Odina wodier*.

4. In sedges and grasses the inflorescence axis elongates considerably so that the flowers are brought well above the leaves.

5. Flowers are unisexual.

The direction of the wind is unpredictable. The pollen grains may spread to unwanted places where the female flowers are not found. So there is lot of wastage of pollen. There are some adaptations in these flowers to meet this situation.

6. The accessory whorls of the flower namely the calyx and corolla are reduced in size and are not brightly coloured and are not scented.

7. Enormous amount of pollen grains are produced.

8. The pollen is dry, loose and powdery, so that it is easily carried by the wind.

9. The filaments are long and exserted. The anthers are versatile so that they swing freely on the filament even with a small breeze of wind.

10. The stigmas are specially adopted for catching the pollen. They are usually long and feathery and are hanging out of the flower.

III. Zoophily or pollination by animals

These flowers are said to highly evolved than the other two types. There are several groups of animals which help as agents and are accordingly named.

A. Bat—Chiropteriphily

B. Birds—Ornithophily

Characters found in Entomophilous flowers

1. *Conspicuousness:* These flowers are large when solitary; or found in inflorescence when small.

2. *Colour:* These flowers are usually brightly coloured. Usually the corolla is coloured and attract the insects. But the function of attraction may also be carried out by other floral parts like bracts (*Bougainvillea*) one of the sepals (*Mussaenda*) stamens (*Mimosa pudica*) stamens and style (*Canna indica*)

3. *Scent:* Scent attracts the insects. Generally the flowers which will open during night are scented (e.g.) *Cestrum nocturnum.* These flowers are white in colour which is conspicuous during darkness.

4. *Food for the insects:* In addition to the colour and scent, the flowers offer food for the insects.

(*a*) *Edible pollen:* These are called *pollen flowers.* They offer pollen as food for the visiting insects. (e.g.) *Cassia marylandica*, *Anemone* and *Verbascum.*

(*b*) *Honey:* These are called *honey flowers.* These flowers offer honey for the visiting insects. (e.g.) *Cotoneaster*, *Saxifraga*

(*c*) *Edible sap:* In *Orchis*, juicy cells of the spur offers sap for the visiting insect.

5. The flowers open accordingly to the nature of the insect visitor. The butterfly and bees are active during the daytime (diurnal). So these visit the flowers which open during the day-time.

Moths are active during night (nocturnal) and visit the flowers like *Nyctanthus*, *Morinda*, which open during night.

6. The pollen grains are with small outgrowths by which they can easily stick on the body of the insects.

7. The stigma is also sticky and receptive to the pollen.

8. The pollen output in these flowers are limited and so there is no wastage of pollen grains as in wind-pollinated flowers.

ECONOMIC IMPORTANCE OF FLOWERS

Flowers are chiefly cultivated for their beauty as ornamentals. There are various colours of flowers to satisfy the tastes of different people. Some of the flowers are cultivated for extracting the essential oils, medicine, etc.

1. All the Hindu religious ceremonies are celebrated only with flowers. Gods are decorated with garlands made of Jasmine, Rose, Oleander and Chrysanthemum. All the festivals and marria-

ges are celebrated only with flowers. Indian women are fond of adorning their hair with flowers.

2. Aromatic oil present in the petals of flowers are extracted and used for making perfumes, cosmetics and soaps.

Scent is prepared from the petals of rose flowers (Otto of roses) *Citrus aurantium*, (*Neroli*) *Viola odorata* (*violet*) *Jasmine glandiflorum*. (Jamine oil) *Michelia champaka*. (Champaca)

3. Some of the flowers are taken as vegetables. (e.g.) Plantain flowers, Moringa, Cauliflower.

4. *Dyes:* Dyes are extracted from the flowers of *Carthamus tinctorius*, *Butea frondosa* and *Cedrela toona*.

5. *Medicines.*

(*a*) Santonin is extracted from unopened flowers of *Artemssia cina* and is much used to remove worms from the intestines.

(*b*) Clove oil is prepared from the dried flower buds of *Eugenia caryophyllata* which is used as a medicine to relieve the pain due to tooth ache. It is also used in microtechnic and preparation of stains.

6. *Spices:*

(*a*) Flower buds of *Eugenia caryophyllata* is used as a spice to give special flavour to our dishes.

(*b*) The dried stigmas and tops of styles of *Crocus sativus* are also used as a spice.

7. *Fibres:* Fibres are obtained from the inflorescence of *Sorghum vulgare ver-technicum* and is used in making brushes.

8. *Beverages.* The inflorescence axis is incised and the exudating sap is used to prepare the intoxicating drinks from coconut, palmyra etc. Gur is also prepared from this.

9. *Honey:* Honey is used as a food and medicine. Flowers secrete a sweet substance namely the nectar which attract the insects. Insects take it as a food and after partial digestion convert it into honey.

10. Gardens contain different kinds of flowering plants which are cultivated for their beauty.

Chapter VI

FRUITS AND SEEDS

FRUIT

Fruit can be defined as a fertilized and ripened ovary. There are two portions contained in a fruit namely the *pericarp* and the *seeds.* After fertilization the ovary wall becomes the pericarp and the ovules become seeds.

When the ovary part of the flower becomes a fruit, it is known as a *true fruit* when any other part of a flower such as the thalamus or the calyx also grows and forms a part of the fruit, then it is called as a *false fruit* or *pseudocarp.*

When the fruit is developed from a single flower bearing a single pistil, whether monocarpellary or syncarpous, it is referred to as a simple fruit.

When it is developed from a single flower bearing many apocarpous pistils, then it is called an aggregate fruit.

Classification of Fruits

Classification of fruits is given separately. Fruits whether true or false may be classified into simple, aggregate and multiple fruits.

Simple Fruits

Based on the fleshy or dry nature of the pericarp, simple fruits are further classified into *fleshy fruits* and *dry fruits.* In the dry dehiscent fruits, pericarp splits open and liberates the seeds. In dry indehiscent fruits, the pericarp never breaks open to liberate the seeds.

Simple Fleshy fruits

Fleshy fruits are normally indehiscent and their seeds are freed only after the decay of the pericarp.

1.*Berry:* The whole fruit is fleshy derived from multicarpellary, syncarpous ovary. There are usually many seeds as in

Tomato, Grapes, Brinjal, Plantain. There are also one seeded berries that are developed from monocarpellary pistil as in date palm, *Artabotrys* etc.

The pericarp is thick and succulent. It is differentiated into an outer *epicarp*, middle *mesocarp* and inner *endocarp*. The epicarp is thin and forms the skin of the fruit. The mesocarp and endocarp regions are fused to form the inner pulp which encloses the seeds (Fig. 6.1).

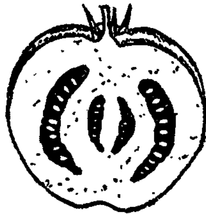


Fig. 6.1 Berry

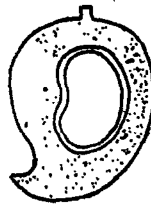


Fig. 6.2 Drupe

2. *Drupe:* Here the fruit wall or pericarp is clearly demarcated into epicarp, mesocarp and endocarp. The endocarp is hard and stony. The fruit is derived from monocarpellary or multicarpellary syncarpous pistil. In Mango the epicarp and fleshy mesocarp form the edible portion of the fruit. In coconut, the mesocarp is fibrous enclosing a number of air-spaces which is used to float in water and help the fruit in water dispersal. (Figure. 6.2).

In *Ziziphus* there are 2 seeds inside the endocarp and the drupe fruit with more than one seed is called a *Pyrene*

3. *Hesperidium:* It is developed from superior multicarpellary, syncarpous pistil. Here the pericarp is clearly differentiated into epicarp mesocarp and endocarp. The epicarp is thick, leathery and contain oil glands. Next to it is the mesocarp which is white and spongy. The innermost thin papery endocarp forms a number of partitions which divide the fruit into a number cells. From the inner walls of the endocarp, large number of juicy, succulent hairs are formed which constitute the edible portion of the fruit. (e.g.) Orange, Lemon (Fig. 6.3).

4. *Pepo:* This is developed from an inferior, tricarpellary syncarpous pistil which is the characteristic fruit of the family

Cucurbitaceae like *Cucumis sativa, Cucurbita maxima* etc. The epicarp is thick and leathery. The mesocarp along with thick fleshy placenta are the edible portions of the fruit (Fig. 6.4).

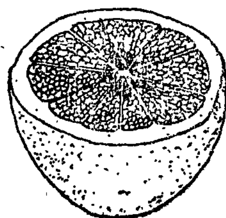


Fig. 6.3 Hesperidium

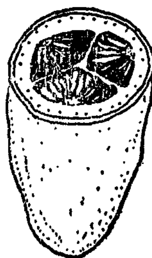


Fig. 6.4 Pepo

Simple dry dehiscent fruits

A. Fruits developed from monocarpellary pistil

1. *Legume or Pod:* Here the pericarp is dry rough and hard. At maturity it splits open along both the margins and liberates the seeds (e.g.) pulses (Fig. 6.5.).

2. *Follicle:* In this type, the pericarp breaks along the ventral suture alone, where the seeds are attached and thereby the seeds are liberated (e.g.) *Calotropis, Michelia champaka, Asclepias* (Fig. 6.6.).

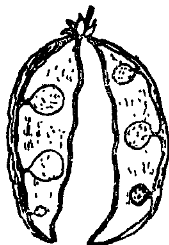


Fig. 6.5 Legume

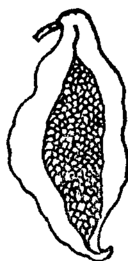


Fig. 6.6 Follicle

B. Fruits developed from syncarpous pistils

1. *Capsule:* This type of fruit is derived from multicarpellary, syncarpous pistil. There are many types of capsules variously named accordingly to their mode of dehiscence (Fig. 6.7)

(a) Loculicidal capsule: Here the pericarp splits longitudinally along the middle of each locule into as many valves as there are carpels and expose the seeds. (e.g.) *Abelmoschus esculentus*, cotton.

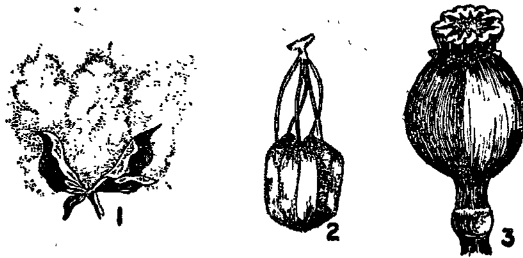


Fig. 6.7 Capsule
1. Loculicidal capsule 2. Septicidal capsule 3. Porous capsule

(b) Septicidal capsule: Here the pericarp breaks longitudinally along the partitions or septa and liberate the seeds. (e.g.) *Aristolochia indica*.

(c) Septifragal capsule: Here the pericarp breaks longitudinally along the locule or along the septa the valves fall away leaving the seeds attached to the central axis (e.g.) *Datura*, *Legerstroemia*.

(d) Porous Capsule: The mature fruit has got a number of small openings or pores on the top of the fruit and the seeds are liberated through them. (e.g.) *Papaver somniferum*.

Dry Indehiscent fruits

The pericarp never breaks open. The seeds are liberated only after the decay of the pericarp (Fig. 6.8).

1. *Achene:* This is developed from superior ovary. The fruit is one celled and one seeded. The pericarp is dry, membranous and free from the seed coat.

2. *Caryopsis:* This is also an one celled and one seeded fruit. The dry membranous pericarp is fused on all sides with the seed coat (e.g.) Paddy, Wheat.

3. *Cypsela:* It is smilar to the achene, but is developed from an inferior ovary. (e.g.) *Tridax*, Sunflower,

4. *Nut:* It is just a modification of an achene in which the fruit is large with hard thick and woody pericarp (e.g.) *Cashewnut.*

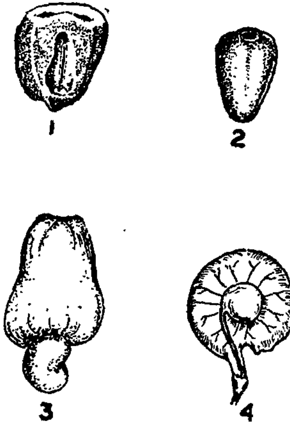


Fig. 6.8 Dry indehiscent fruit
1. Caryopsis 2. Cypsela 3. Nut 4. Samara

5. *Samara:* A winged achene is called a samara. Here the pericarp grows out into a thin winglike expansions and help in the dispersal of fruits. (e.g.) *Pterocarpus, Acer.*

Schizocarpic fruit

A schizocarpic fruit consists of many one seeded parts or



Fig. 6.9 Schizocarpic fruits
1. Lomentum 2. Cremocarp 3. Regma

Cocci. The fruit first breeks into one seeded mericarps, but the mericarps enclosing the seeds remain indehiscent (Fig. 6.9.).

1. *Lomentum:* When the legume is partitioned between the seeds or constricted into a number of one seeded parts it is called a lomentum. (e.g.) *Acacia arabica.*

2. *Cremocarp:* This is developed from inferior, bicarpellary, syncarpous ovary. At maturity, the fruit breaks into two indehiscent one seeded fruitlets called mericarps. (e.g.) Fruits of *Umbelliferae* family like *Coriandrum sativum, Cuminum cyminum.*

3. *Regma:* Here the fruit first spilits into one seeded *Cocci*, then each *Coccus* dehisces further loculicidally and liberate the seeds (e.g.) Castor.

DISPERSAL OF FRUITS AND SEEDS

Generally, the fruits and seeds are disseminated away from the parent plant and this is referred to as dispersal. The biological significance of the phenomenon can be justified by the following points.

1 If a plant bears numerous seeds and all of them fall and germinate right beneath the parent plant, the seedlings would compete for space, water, minerals and sunlight, leading to competition and survival of the fittest.

2. When the seedlings are grouped together at one place they could easily be detached by grazing animals and destroyed.

3. If a group of plants grow together in a limited locality inbreeding occurs mainly, thus leading to degeneration.

4. If the seedlings are crowded together, they are much more vulnerable to epidemics like attack of fungi and insects which may lead to the complete extinction of the species.

5. Most of the plants are rooted in the soil at one place and are immobile. They are not helpful in establishing the species in a new area.

To guard against these contingencies fruits and seeds have developed many special devices for their wide distribution with the result that some of them at least are likely to meet with favourable conditions for germination and growth.

It is thus evident that the risk of a species of a plant becoming extinct is reduced to a minimum. The dispersal mechanism of fruits and seeds are as follows.

1. Autochory: Where some plants have built in devices for dispersal to considerable distances.

Majority of the plants depend on certain external agencies such as wind, water and animals for dispersal.

2. Anemochory—dispersal by wind
3. Hydrochory—dispersal by water
4. Zoochory—dispersal by animals

I. Autochory: In *Ecbalium elaterium*, the content of the fruit remains under pressure and its stalk acts like a stopper. When the fruit ripens it is detached from the stalk. The internal pressure is released and the internal contents are "squirted" out with force up to a distance of 20 feet (Fig. 6.10).

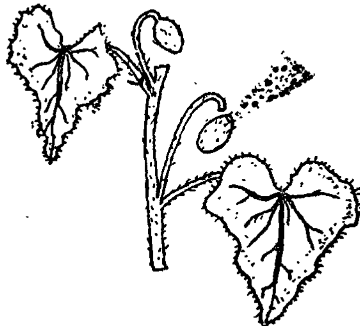


Fig. 6.10 Autochory

II. Anemochory: The fruits and seeds dispersed by wind have to be light and thin so that they can float in the air for con-



Fig. 6.11 Anemochory
1. Tridax 2. Calotropis 3. Cotton 4. Clematis

siderable distances. They are specially adopted for wind dispersal and have the following characters (Fig. 6.11)

1. Very small dust like, seeds are easily carried away, by the wind. (e.g) Orchid seeds.

2. Certain seeds and fruits are provided with appendages which act like parachutes for dispersal.

(*a*) *Pappus* is the modification of calyx in the fruits of *Compositae* family.

(*b*) Coma is a tuft of hair developed on the tip of the seeds to help in dispersal (e.g.) *Calotropis*.

(*c*) Hairy outgrowths found on the seeds as in *Cotton*.

(*d*) Persistent hairy style of *Clematis* and *Naravelia* help them to float in the air.

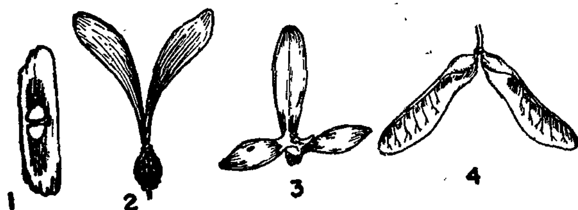


Fig. 6.12 Anemochory
1. Winged seed 2, 3, 4. Winged fruits

3. *Wings* are developed in fruits and seeds rendering them to float in the air (Fig. 6.12).

(*a*) Winged seeds are seen in *Tecoma stanes*, *Oroxylum* and *Cinchona*.

(*b*) Samaroid fruits are found in *Gyrocarpus*, *Hiptage* and *Acer* help them in dispersal.

4. *Cancer Mechanism*: In certain fruits, the seeds are discharged through small openings on the fruits. Thus in *Argemone mexicana* and the *Pappier*, after the apertures are opened by porous dehiscence, the minute seeds are dispersed through pores, as the capsule swings in air.

III. Hydrochory: The fruits and seeds of the plants growing along the water side are dispersed by water. (e.g.) Fruits of coconut, *Cerebera odullum*, *Pandanus*.
Such fruits must be provided with a coat which is simultaneously waterproof, salt resistant and buoyant.

The dry fibrous mesocarp which includes several air spaces render them suitable for this purpose. Water lilies are dispersed by spongy thalamuses (Fig. 6.13).

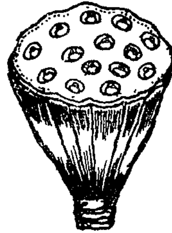


Fig. 6.13 Hydrochory
Lotus

IV. Zoochory: Some fruits are eaten by animals and the seeds are passed out with the excreta unharmed and this is called *endozoochory.* If the fruits and seeds are carried by the animals externally, sticking to their bodies or held in their mouths it is known as *exozoochory.*

Sometimes, fruits and seeds are provided with appendages or sticky secretions which facilitate their dispersal by animals.

1. Fruits and seeds of many plants are provided with *Spines, hooks, barbs* or *stiff hairs* so that if an animal comes into contact with these fruits, they stick to their body and may be dropped far away from the parent plant. (e.g) *Martynia diandra, Achyranthes aspera, Pupalia, Tribulus* etc., (Fig. 6.14).

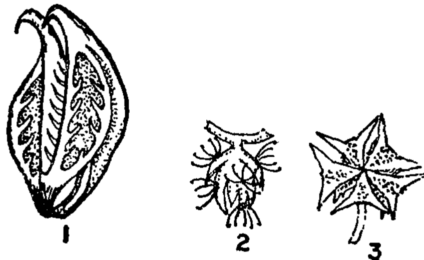


Fig. 6.14 Zoochory
1. Martynia 2. Pupalia 3. Tribulus

2. A few fruits like *Cleome viscosa* and *Boerhaavia repens* have sticky glands so that they can stick to the body of the animals and get dispersed.

Man has been responsible in the dispersal of several fruits, and seeds. Whenever he moves in a field from one place to another he carries the fruits and seeds without his knowledge and thus they are dispersed.

While consuming fruits like *Mango* and *Citrus* varieties, he takes only the edible portion of the fruit, throwing away the seeds so that they are dispersed.

Man is responsible for the dispersal of many fruits and seeds in the pursuit of more economically useful plants. Even a plant like *Capsicum fruitescence* was introduced in India by man. Plants like Rubber, *Cinchona* and *Eucalyptus*, have been successfully introduced by man and they have acclamatised well to the new surroundings far away from their original homes.

SEED

Seed is a fertilised mature ovule, consisting of an embryonic plant and protected by seed coats. There is a great variation regarding the size, shape and colour of the seeds.

Germination: All the changes that take place from the time the seed is put in the soil to the time a young plant is deveolped from it are included under the term germination. During germination the dormant embryo is made to begin its activities with the necessary environmental and internal conditions.

CONDITION NECESSARY FOR GERMINATION

A. External Conditions

1. *Moisture:* Sufficient quantity of water is essential for the seeds to germinate. Seeds absorb moisture and resume their vigorous physiological activities. The food material contained in the cotyledons or endosperm is digested and supplied to the developing embryo Water is necessary for digestion, respiration and conduction of the food.

2. *Oxygen:* Oxygen is necessary to awaken the seed to respire and to begin physiological activities.

3. *Optimum temperature:* Like all physiological activities germination is also affected by temperature. There is a minimum temperature to indicate the germination an *Optimum temperature* where it is most satisfactory and maximum temperature, beyond which germination cannot take place.

4. *Light:* It has been found out that germination of 70% of seeds is favoured by light, in about 26% of seeds light inhibits germination, while about 4% of seeds are indifferent to light.

B. Internal Factors

1. *Food and auxins:* All the seeds contain reserve food material either in the cotyledon or in the endosperm. Auxins are growth promoting substances essential for germination.

2. *Dormancy:* Many seeds will not be able to germinate as soon as they are discharged from the plants. They require a period of rest known as *dormancy period* which varies from species to species. This is advantageous to the plant since it enables the embryo to safely pass the unfavourable part of the year and germinate when the conditions are favourable.

3. *Viability:* Viability is the capacity of the seed to germinate. Seeds are viable only for a definite period of time after which the embryo becomes dead for all practical purposes. Viability of the seeds may vary from one growing season to many years according to the species.

STRUCTURE OF THE BEAN SEED

The seed is bulky, oval and slightly indented on one side. On this side there is a longitudinal whitish ridge formed by the funicle called *raphe*. There is a opening called the *micropyle* at one end of the *raphe*. At the other end of the raphe is the chalaza. The seed has got two *seed coats* the outer known as *testa* and the inner *tegmen*. Inside the seed coat is the embryo. It consists of two fleshy cotyledons, attached to the primary axis. The primary axis has a rudimentary root portion called the *radicle* and a rudimentary stem portion called the *plumule*. The tip of the radicle points towards the micropyle. The plumule is seen in between

the two cotyledons and consists of a short axis and a small bud having two tiny little folded leaves. There is no endosperm in the mature seed (Fig. 6.15).



Fig. 6.15 Structure of the bean seed
1. Cotyledon 2. Hilum 3. Plumule 4. Radicle

Germination

The seed swells absorbing moisture from the soil. By the activity of the embryo, the radicle grows and comes out of the seed through the micropyle. Due to the pressure exerted by the radicle, the seed coat is ruptured. The radicle grows into the soil and become the primary root.

The hypocotyl begins to elongate. The lower end of the hypocotyl is fixed to the soil and its upper end is attached to the cotyledons which are inside the seed coat. The hypocotyl elongates, resulting in its bending up and coming out of the soil in the form of a loop. The loop begins to grow erect and the two cotyledons

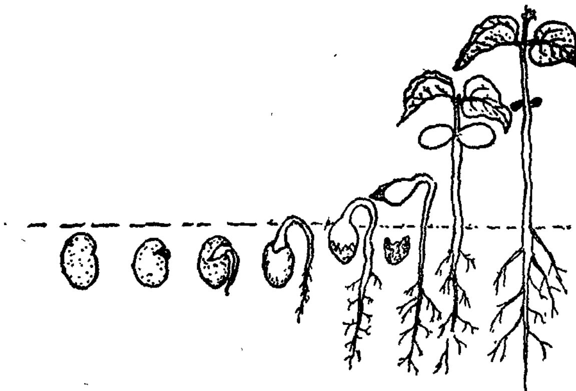


Fig. 6.16 Stages in the germination of bean seed

are pulled out of the seedcoat and brought above the soil. After coming out of the soil the cotyledons separate, spread out on either

side. Now they are light green in colour and are called first pair of leaves of the seedling. The plumule now develops, absorbing food materials from the cotyledons.

In the meanwhile, the primary root develops several lateral roots and firmly fixes itself to the soil. The plumule develops green leaves. The roots absorb water and mineral salts thus becoming an independent plant. Since the cotyledons are brought above the soil level due to the growth of the hypocotyl, the germination is called epigeal (Fig. 6.16).

Chapter VII

VEGETATIVE PROPAGATION

All living organisms are endowed with the capacity of reproduction. Reproduction is the production of new ones similar to the parents. Life cycle of the plant is said to be completed only after reproduction. It is essential to continue the race on the earth.

There are two types of reproduction met within Phanerogams.

1. *Sexual reproduction* which involves union of male and female gametes so as to produce the fruits and seeds.

2. *Vegetative propagation or vegetative reproduction:* When new plants arise from cut portions of the old plant the method is known as vegetative propagation. This is found in many plants and is extensively exploited in the production of many garden plants.

There are many methods of vegetative propagation

1. *Cutting:* In *Moringa* or *Thespesia* plant, if a branch with nodes and internodes is cut and planted in the soil it will develop buds and roots and become an independent new plant. The separated branch is called a *cutting.* In sugarcane only a small portion of the stem consisting of the bud and node known as 'set' can give rise to a new plant.

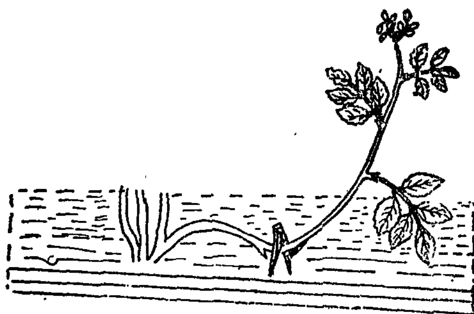


Fig. 7.1 Layering

2. *Layering:* In the case of Jasmine and *Nerium, Odorum* a portion of the plant is bent down after removing of the bark

and covered with soil. When this portion is watered well, it will develop into a fresh plant after a few days. Even if the portion is cut off from the mother plant, it can lead an independent life. This method of vegetative propagation is called layering (Fig. 7.1).

3. *Aerial stems:* Some of the weak stemmed plants like runners and stolons develop a number of daughter plants in the course of their growth and help in the vegetative propagation of these plants. (e.g.) *Hydrocotyl asiatica.*

4. *Underground stems:* Underground stems are very useful to store large quantities of food materials safely kept underneath the soil beyond the reach of the grazing animals. In addition to this they are very helpful in the vegetative propagation of these plants within a short time.

Underground stems like rhizome (Ginger) corm (Colocassia) tuber (Potato) and bulb (Onion) contain axillary buds and terminal buds which help to develop into many new plants.

5. *Adventitious buds:* Normally buds are seen in plants as terminal and axillary buds. If the buds are found in any other part of the plant such as leaves, inflorescence etc, those buds are called adventitious buds.

(*a*) *Buds on roots:* In *Millingtonia, Psidium guajava, Cassia fistula* and Morgosa tree, buds are developed on the roots and they give rise to new plants.

(*b*) *Buds on leaves:* When portions of the leaf are covered with moist soil, adventitious buds and roots are formed which give rise to new plants as in *Begonia.*

In *Bryophyllum* if the leaf is tied to a thread and suspended in moist air, adventitious buds and roots develop from the margins of the leaf which are capable of giving rise to new plants.

(*c*) *Bulbils:* Sometimes the buds are modified into peculiar structures called bulbils which on separation give rise to new plants under favourable conditions,

In *Scilla* such bulbils are seen on the leaftips. In *Dioscorea bulbifera* bulbils are seen in the axils of leaves and serve for vegetative propagation. The large inflorescence of *Agave americana* shows many of its floral buds transformed into bulbils which begin to germinate while it is still on the inflorescence. Such transformation of flower-buds into bulbils is also seen in *Allium sativum* and *Globba bulbifera*. In *Oxalis* bulbils occur on the swollen root.

Advantages:

1. New plants can be developed within a short time by different methods of vegetative propagation.

2. The characters of the mother plant is faithfully reproduced in the daughter plants. Even in hybridisation techniques after evolving a new strain superior in all respects, it is multiplied by vegetative propagation to preserve the old traits.

Disadvantages:

There is no possibility of introducing new characters in the progeny in the method of vegetative propagation.

Grafting

In the cutting and layering methods of vegetative propagation, there is no possibility of improving the quality of the strain, but in grafting the quality of the existing variety can be improved. The existing variety is known as the *Stock* and the superior variety is called the *Scion*. The two plant portions are made to unite and the quality of the yield will be improved to that of the scion variety There are three methods of grafting.

1. Approach grafting
2. Stem grafting
3. Bud grafting.

1. *Approach grafting:* This is a simple and largely practised method of grafting. The superior variety with which grafting is attempted is grown in the soil. The stock variety is grown in a pot. When both the stock and the scion reach about 1.5 cm in thickness they are brought near each other. A shallow slice of stem is removed from the stock and scion.

They are brought into contact with each other and held firmly in position by means of grafting tape. The graft portions are kept moist so that the tissues are organically united. After the union is complete the base of the scion and the top of the stock are severed below and above the level of the grafting portion. When the yield is obtained it will have the quality of the scion.

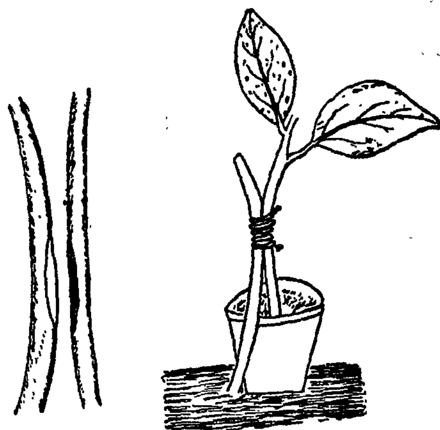


Fig. 7.2 Approach grafting

This method of grafting is practised in grafting the economically important plants like Mangoes, Sapotas and Guavas (Fig. 7.2).

2. *Stem grafting:* The Scion and Stock are selected in such a way that they are equal in thickness. The tip of the scion and stock are cut obliquely and cut surfaces are brought together by bandaging tightly with tape. Thus the stock and scion are held firmly in position. Sufficient moisture is provided in the graft portion by the application of clay or grafting wax. This type of grafting is also known as *whip grafting*. All buds are removed from the stock but not from the scion.

3. *Bud grafting:* Here grafting is not done between two equal portions of stock and scion. It is done between the bud of a scion to the portion of the stock plant.

A portion of the stem with its axillary bud is taken as the scion. A T-shaped incision is made in the stock portion of the plant.

The scion portion is placed in the incision of the stock and held firmly in position by bandaging carefully with tape. The scion

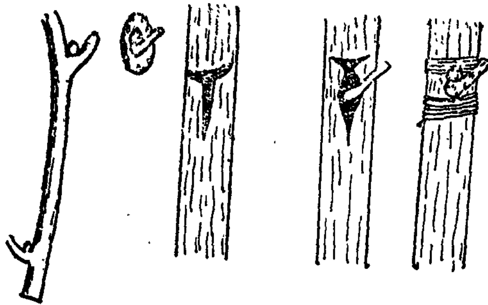


Fig. 7.3 Bud grafting

absorbs water and minerals from the stock and develops into a plant of superior variety. (e.g.) Apple, Orange and Rose. (Figure 7.3)

4. *Advantages of grafting:*

(*a*) The yield is obtained earlier by grafting five year old portion of the scion to one year old stock (e.g.) Mango.

(*b*) The quality of the fruits and flowers can be imporved.

(*c*) Period of life of the plant can be extended by grafting portions of annuals to the perennials.

(*d*) Better and new varieties of fruits and flowers can be obtained by grafting.

Limitation: There is one limitation in grafting namely that it is possible only between closely related plants.

Chapter VIII

GROWTH AND MOVEMENTS

GROWTH

Growth is an important characteristic feature of living things. It is rather difficult to define "growth". The essential feature about growth is the production of new cells which is accompanied with an increase in size and weight . Growth is not merely an increase in size or weight of an organism. It is always accompanied by a process called development which involves a progressive change in form i.e. production of leaves, branches, flowers etc. Therefore growth may be defined as a permanent and irreversible increase in size and form of an organism accompanied by an increase in dry weight.

Growth in plants is generally restricted to regions of growing points called meristems. The apical meristems present in the root apex and the shoot apex are responsible for growth in length. In certain plants like grasses, increase in length is also, due to intercalary meristems present at the nodes. Growth in thickness is brought about by the lateral meristem namely cambium.

STAGES OF GROWTH OR PHASES OF GROWTH

Growth of any organ of a plant shows three distinct stages or phases.

1. *Formative stage*: In this stage, meristematic cells divide and multiply in number.

2. *Stage of enlargement or elongation*: In this stage, the newly formed cells enlarge in size and elongate.

3. *Stage of maturation*: In this stage, the elongated cells get specialised to form various tissues and attain maximum size.

Regions of Growth

Corresponding to the three stages, at the tip of a stem or root, three zones of growth are recognised. At the extreme tip is the

formative zone or regions of cell formation. Just behind this is the zone of elongation or region of cell enlargement. Following this is the zone of specialisation or region of maturation.

These three zones of growth in a root tip can be shown by means of a simple experiment. A germinating bean seed with a root (i.e. radicle) about an inch long is selected. The root is marked from the tip upwards at equidistant intervals with waterproof Indian ink. The seed is pinned to a cork pad with the root pointing downwards. It is kept in a moist chamber After

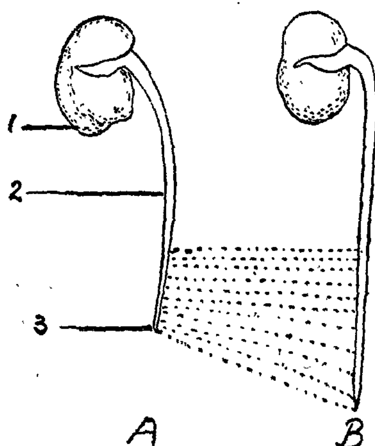


Fig. 8.1 Experiment to show the region of growth
A—Before experiment
1. Germinating bean seed 2. Root 3. Root tip
B—After experiment

a few days it is seen that the lines at a little distance behind the tip become widely separated whereas lines in the other regions remain more or less same. This shows that maximum elongation takes place behind the tip. (Fig. 8.1)

Course of Growth

Growth of a cell, an organ or a plant does not take place at the same rate even if the external conditions are uniform. To start with, the growth is slow but increases rapidly to a maximum and then decreases slowly. The total period during which these changes

take place at the time of growth is called the "grand period of growth."

Measurement of growth: The rate of growth can be measured by using an apparatus called a lever auxanometer or arc indicator.

The lever auxanometer consists of a scale in the shape of an arc, fixed to a stand. The scale is attached to a pulley with a long pointer. As the pulley rotates the pointer moves on the scale. A thread is attached to the growing end of a plant and is allowed

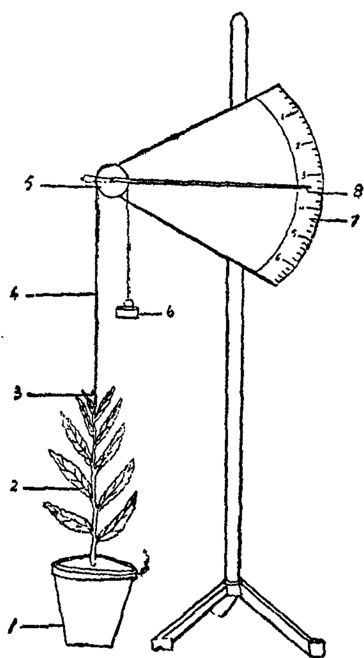


Fig. 8.2 Lever auxanometer
1. Pot 2. Plant 3. Growing point 4. Thread 5. Pulley
6. Weight 7. Scale 8. Pointer

to pass over the pulley. A small weight is attached to the free end of the thread to keep it in tension. As the plant grows, the weight moves the thread down and this moves the pulley. The

needle also moves on the scale. The growth of the plant in length is thus magnified on the scale (Fig 8.2).

$$\frac{\textit{Length of the pointer (for e.g. 20")}}{\textit{Radius of the pulley (for e.g. 2")}} = \text{magnification (i.e. 10")}$$

$$\frac{\textit{Number of divisions covered by pointer (for eg. 4")}}{\textit{magnification (i.e. 10")}} = \frac{4}{10} \text{ or } .4"$$

is the actual growth.

Factors affecting growth and development

Growth is influenced by a large number of external and internal factors.

External factors

1. *Temperature*: Growth is a vital phenomenon. It takes place within certain limits of temperature. The minimum temperature at which growth can go on may be 5°C The maximum temperature is variable and lies somewhere between 30°C and 40°C. As the temperature increases from the minimum, the rate of growth also increases. If the temperature exceeds the maximum limit, growth stops and at a still higher temperature, the plant dies. Therefore between the minimum and the maximum, there is a particular temperature at which growth is most rapid and satisfactory. It is called the optimum temperature which is usually between 25°C and 30°C

In many cases, the initial growth rate is higher at a higher temperature (about 35°C) but it soon declines with time. Hence a time factor is said to be operative during growth at higher temperatures. Another striking temperature effect upon growth is the low temperature treatment (or vernalisation) which induces earlier flowering.

2. *Light.* Light is an important factor influencing growth. Growth is usually retarded by light and is accelerated by feeble light or darkness.

Although light has a retarding effect on growth, in the presence of light the plant becomes sturdy and healthy with normal development of the stem and leaves. The plants growing in darkness have elongated but slender stems with elongated internodes and poorly

developed pale yellow leaves. Such plants are said to be etiolated and this condition is called etiolation. Though growth takes place in feeble light or in darkness, plants cannot grow indefinitely in darkness. Light is necessary for the formation of chlorophyll and manufacture of food materials and without sufficient food, growth cannot take place.

The duration of light has marked effect on the growth of plants particularly during the development of flowers and fruits. The length of the daily period of light is called the photoperiod and the response of the plants to the photoperiod is known as photoperiodism.

3. *Water:* An adequate supply of water is essential for growth. Growth stops when there is not enough water in the soil.

4. *Oxygen:* Oxygen is required for respiration. The energy required for growth is obtained from respiration and therefore supply of free gaseous oxygen is necessary for successful growth.

5. *Gravity:* This chiefly affects direction of growth of plant organs.

6. *Chemical influences:* From culture experiments it is found that elements like Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Sulphur etc., are essential for the normal growth of plants. If any one of them is absent, plants do not grow normally.

7. *Mechanical stimuli or forces*: External mechanical factors like contact, also affect the growth. Mechanical contact with support retards the growth of stem of twining plants on the side of contact.

Internal Factors

1. *Food reserves:* Food reserves occur within the plant body and therefore it is considered as internal growth factor. But the synthesis of food material depends upon the proportional to the quantity of stored food reserves.

2. *Carbohydrate-Nitrogen ratio (C/N ratio)*: The ratio between carbohydrate and nitrogen compounds is a major factor which determines whether a plant would show only vegetative growth or becomes reproductive. If only a suitable balance is maintained between available nitrogen and carbohydrate synthesis, both vegetative and reproductive growth are promoted. Deficiency of either the nitrogen or carbohydrate results in the appearance of characteristic and recognisable peculiarities of growth.

3. *Heredity and age*: These are also important internal factors.

4. *Hormones:* Growth of the plant is regulated by certain chemical substances which are synthesised by the plant in very small quantities. These substances are produced in one part of the plant in minute quantities as a result of metabolism and are then transported to other parts where they produce specific effects on growth and development. They are known as plant hormones. They are also known as growth hormones, growth substances, growth regulators, growth factors and phytohormones.

Auxins and Gibberellins are the important growth hormones. In the case of plants, the action of hormones or auxins was first demonstrated on the coleoptile of Oat (*Avena sativa*) by Boysen-Jensen, Stark and more elaborately by F.W. Went and Thimann. During the germination of Oat (and other grass) seeds, a cylindrical structure with a conical top enclosing the plumule grows above the ground level. This structure is known as the coleoptile. It has been observed that when the tip of coleoptile is cut off, growth is retarded. But when the tip is replaced, growth resumed almost at the normal rate. Evidently the tip produces something which when transmitted down the coleoptile induces growth. That something is now known to be auxin.

In another experiment, the tip of the coleoptile is cut off and is placed on a thin layer of agar (3%) for about an hour. The agar is then cut into small blocks and if one such block is replaced on the cut surface of the coleoptile, growth continues. This shows that the auxin produced by the tip of the coleoptile is transmitted to the agar block and from there into the decapitated coleoptile. Further

it is noted that if the agar block is placed on one side of the decapitated coleoptile, growth is more rapid on this side resulting in a

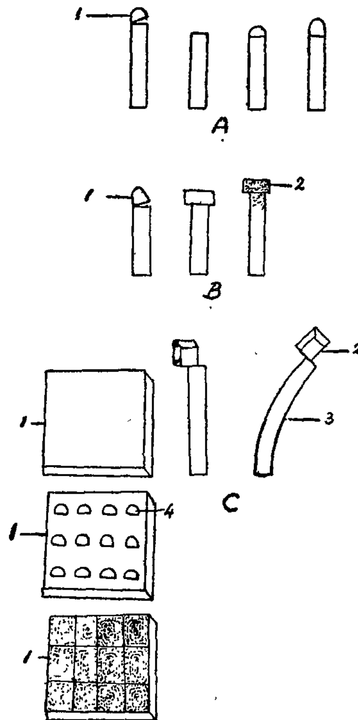


Fig. 8.3 Experiment on oat seedlings
A—Removal and replacement of coleoptile tip
1. Coleoptile tip
B—1. Coleoptile tip 2. Agar block containing hormone
C—1. Agar 2. Agar block 3. Curvature 4. Coleoptile tip

curvature of the coleoptile. Thus the auxin acelerates the growth of this side (Fig. 8.3).

It is thus clear that growth hormones are transported in the plant in the downward direction i.e. from the tip to the elongating region. However, upward conduction also takes place by transpiration.

Chemical Nature of auxins

Kogl and his workers extracted from human urine, three substances capable of promoting growth of plants. They are auxin *a*, auxin *b* and hetero auxin.

Auxin *a* is auxentriolic acid ($C_{18} H_{32} O_5$) and is found in Yeast, Aspergillus and Grasses.

Auxin *b* is auxenolinic acid ($C_{18} H_{30} O_4$) and is found in vegetable oils and Rhizopus.

Heteroauxin is Indole-3-acetic acid ($C_{10} H_9 O_2$) and is found in maize, yeast etc. It can also be synthesised in the laboratory.

Hormones are initially present in plant tissues in the form of their precursors. The precursors are converted into active hormones by enzyme action. (e.g.) Aminoacid tryptophan is the precursor of heteroauxin.

Besides the three natural auxins mentioned above, a number of synthetic substances possessing the properties of auxins have been discovered. They are (1) Phenyl acetic acid (2) α naphthalene acetic acid (3) Indole butyric acid (4) 2-4-Dichloro-phenoxy acetic acid (2-4-D) and (5) 2-4-5 Trichlorophenoxy acetic acid (2-4-5-T).

Practical applications of auxins

Auxins are used in a number of ways both in agriculture and horticulture.

1. Auxins are responsible for initiating as well as promoting cell division and cell elongation
2. Auxins initiate the formation of roots in cuttings.
3. Auxins prolong dormancy; induce fruiting and prevent fruit dropping.
4. Auxins are responsible for the germination of seeds and for the growth of plant organs.
5. Some chemicals bring about the shortening of the internodes.

6. Some prevent lodging of plants (i.e. falling down of plants due to an excessive elongation and softening of cells in the basal internodes) and cause them to grow stiff, woody and erect.

7. Auxins are sometimes responsible for inhibiting the development of lateral buds.

8. Auxins have the effect of breaking the dormancy of bulbs, tubers etc.

9. Auxins generally delay or inhibit flower production but in some cases promote flowering.

10. Auxins produce parthenocarpic fruits or seedless fruits.

11. Certain synthetic substances like 2-4-D (Dichloro phenoxyacetic acid) and 2-2-D (2-2 Dichloro propionic acid) are used in the eradication of weeds.

12. Auxins play an important role in the movement of plant organs in response to light, gravity etc.

Recently another important growth hormone called Gibberellin has been discovered. It brings about a rapid and excessive elongation of the stem. In Japan, the farmers noticed that certain diseased rice plants grew abnormally thin and tall. They called the disease as "Bakanae or foolish seedling disease" It is then found that the disease is due to the infection of a fungus called *Gibberella fujikuroi*. In 1938, Japanese Scientists isolated two active principles from this fungus and called them Gibberellin *A* and Gibberellin *B*. Later British and American scientists obtained another compound from the cultures of this fungus and called it Gibberellic acid. The commercial gibberellin is a mixture of all the three chemicals named above.

1. Gibberellins induce the formation of seedless fruits.

2. They remove dwarfism; stimulate elongation of internodes and accelerate flowering.

3. They stimulate seed germination.

4. Gibberellins are used for breaking dormancy of tubers and seeds.

5. They are also used for the increase in size and yield of fruits like grapes, oranges etc.

Vitamins

Vitamins are organic substances which are synthesised by plants and play an important role in the growth and development For example, Vitamin A plays a role in photoperiodism. Vitamin B_1 (Thiamine) and Vitamin B_7 (Nicotinic acid) are essential for normal root development in green plants. Vitamin B_2 (Riboflavin) involves in some metabolic activities. Vitamin C (Ascorbic acid) acts as a catalyst in photosynthetic phosphorylation, Vitamin K is a regulator of oxidation-reduction processes in living cells and acts as a catalyst in the cyclic electron transport during photosynthesis.

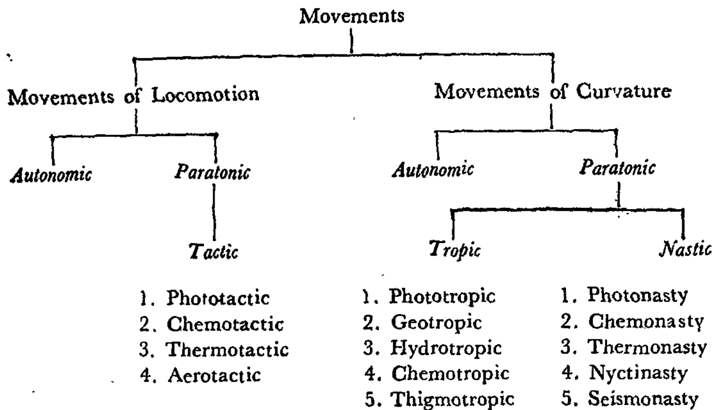
MOVEMENTS

Plant movements are broadly classified into two categories (1) movements of locomotion and (2) movements of curvature. When the plant or the plant parts move bodily from one place to another, it is called movement of locomotion (e.g.) Chlamydomonas. When the plant parts move usually in the form of curvature, it is called movement of curvature (e.g.) movements of stem tip, root tip etc.

Movements in plants are influenced by certain external and internal factors. The factors which induce the movements are called stimuli and the reaction of the plant to the stimulus is called the response. The irritability or sensitiveness i.e. response of a plant to stimulus is an important property of protoplasm.

Movements whether locomotory or curvature may be either spontaneous or induced. The movements which take place spontaneously i.e. without the effect of external stimuli like light, gravity etc. are termed spontaneous or autonomic movements. The movements which are caused by external stimuli are called induced or paratonic movements. The paratonic movements are usually of three types namely tactic movements, tropic movements and nastic movements.

Classification of Plant Movements



Tactic	Tropic	Nastic
1. Phototactic	1. Phototropic	1. Photonasty
2. Chemotactic	2. Geotropic	2. Chemonasty
3. Thermotactic	3. Hydrotropic	3. Thermonasty
4. Aerotactic	4. Chemotropic	4. Nyctinasty
	5. Thigmotropic	5. Seismonasty

Tactic movements

Tactic movements are movements of locomotion which are induced by external stimuli. The common tactic movements are:

1. *Phototactic movements*: Phototactic movement is the movement of an organism in response to the stimulus of light. For example, Algae move towards the source of light when the light is weak but when light is strong, they move away from the light

2. *Chemotactic movements*: The movement of an organism in response to the stimulus of chemical substances is known as chemotactic movement. (e.g.) The antherozoids of plants like bryophytes move towards the archegonia due to the attraction of certain chemical substances like malic acid secreted by the archegonia.

3. *Thermotactic movements*: Thermotactic movement is the movement of an organism in response to the stimulus of heat. If a vessel containing water with chlamydomonas is warmed on one side, the algae move towards the warm side in response to heat. But when the water becomes hotter on that side, they move away from that side.

4. *Aerotactic movement*: This is the movement of an organism in response to the stimulus of air. (e.g.) Bacteria move to places where the oxygen concentration is high.

Tropic movements or Tropisms

Tropic movements are induced movements in which the direction of the movement is determined by the direction of the stimulus. Depending upon the nature of the stimulus, the following kinds of tropisms are recognised. (1) Phototropism (2) Geotropism (3) Hydrotropism (4) Chemotropism and (5) Thigmotropism

1. *Phototropism:* The movement of curvature in response to light is called phototropism. It is also known as heliotropism. The stem is positively phototropic because it grows towards the light. The root is negatively phototropic because it grows away from the light. The leaves grow at right angles to the direction of light and therefore they are known as diaphototropic or transversely phototropic.

Phototropism can be demonstrated by keeping a pot plant inside the phototropic chamber (or dark chamber). The chamber consists of a rectangular wooden box, painted black on all sides and is provided with a small opening on one side through which light can pass. After a few days, the stem tip curves and grows towards the opening i.e the source of light. This experiment proves that the stem is positively phototropic.

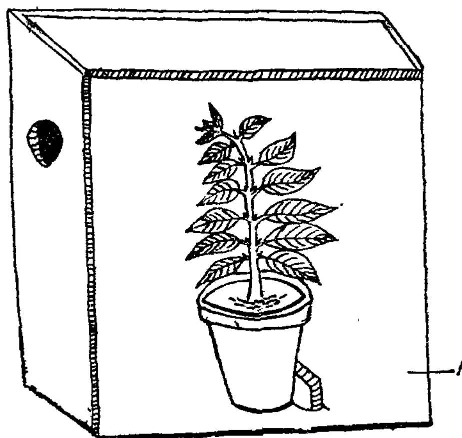


Fig. 8.4 Experiment to demonstrate phototropism
1. Dark chamber box

The mechanism of phototropic curvature is believed to be due to auxins. When a plant is subjected to illumination on one side,

the auxins accumulate in the shaded side. As a result of this, the stem bends or curves towards the light (Fig. 8.4).

2. *Geotropism:* Geotropism is the movement of curvature in response to the stimulus of gravity. The root is positively geotropic because it grows towards the centre of gravity. The stem is negatively geotropic because it grows against the force of gravity. Lateral roots and branches grow at right angles to the force of gravity and they are called diageotropic or transversely geotropic.

Geotropism can be shown by a simple experiment. A potted plant is kept in a horizontal position. After sometime the shoot tip bends upwards and becomes vertical. This is due to geotropism.

When a plant is kept horizontally and rotated on its own axis, there is no curvature. This can be demonstrated by an instrument called Klinostat. It consists of a rod with a disc attached to one end and a clock work mechanism for rotating the rod and the disc. A small pot plant is attached to the disc and the Klinostat is placed in a horizontal position.

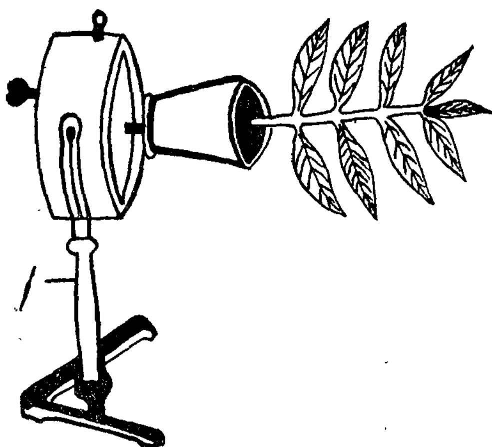


Fig. 8.5 Experiment to demonstrate geotropism
1. Klinostat

The clock is made to work. The plant gets rotated slowly on its axis It is noticed that the plant continues to grow horizontally without curving because gravity is made to act on all sides of the

plant equally. Therefore the effect of gravity is nullified. If however, the clock is stopped, the horizontal stem tip curves up (Fig. 8.5.).

Geotropic curvature is caused by the activity of auxins, when the plant is placed *horizontally*, the auxins accumulate on the lower side. In the case of stem, accumulation of auxins on the lower side accelerates growth and therefore the stem bends upwards. But in the case of root, the excess hormone retards growth and therefore the root bends downward.

3. *Hydrotropism:* The movement of curvature exhibited by roots in response to the stimulus of water or moisture is called hydrotropism. Roots are positively hydrotropic. This can be demonstrated with germinating seeds. These seeds are allowed to grow in a sieve containing

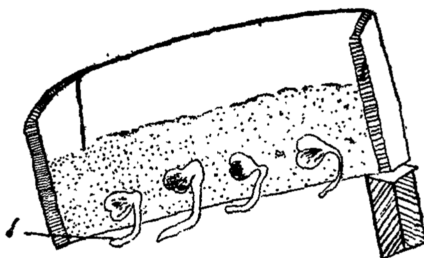


Fig. 8.6 Experiment to demonstrate hydrotropism
1. Root of the seedling

moist saw dust. The sieve is then kept in an inclined position. The concentration of water will be greater in the lower half than in the upper. At first the roots grow in a downward direction due to the stimulus of gravity but then they bend and grow along the sieve towards the lower side where there is greater concentration of water. This shows that roots are positively hydrotropic. Moreover, here, hydrotropic stimulus is greater than that of gravity (Fig. 8.6).

4. *Chemotropism:* The movement of plant organs in response to chemical influences is known as chemotropism. Pollen tube grows through the style towards the micropyle being induced by substance secreted by the stigma.

5. *Thigmotropism:* Thigmotropism is the movement in response to the stimulus of contact. This is seen in the case of tendrils. If the tip of the tendril comes in contact with a support, it exhibits movement.

Nastic Movements

Nastic movements are caused by external stimuli but the direction in which the movement takes place depends upon internal factors and not on the direction of the stimulus. The stimulus influence the organ with equal intensity from all directions. Usually leaves and petals show nastic movements. Depending upon the nature of the stimulus, the nastic movements are of the following types.

1. *Photonasty*: This is the movement brought about by a change in the intensity of light (e.g.) lotus flower opens on illumination and closes on darkness.

2. *Chemonasty*: Chemonasty is the movement induced by chemical substances. If substances like albumin, phosphate etc, is placed in the centre of the leaf of Drosera, the tentacles move towards it.

3. *Thermonasty:* The movement induced by a change in the temperature of the surroundings is called thermonasty. Leaves and flowers open when the temperature is high and close when the temperature is low.

4. *Nyctinasty:* Nyctinasty, also known as sleep movement, is the movement induced by the alternation of day and night. Leaflets of plants belonging to the family Leguminosae exhibit this kind of movement. The leaves of the rain tree fold and hang down during night time, as though in sleep. But they assume their normal shape or position again in the morning.

5. *Seismonasty*: Seismonasty is the movement induced by mechanical stimuli such as contact or touch. This is seen in the sensitive plant, *Mimosa pudica*. In this plant, the leaves are bipinnate; the main rachis and the secondary rachii are pulvinate. If a tip of a leaflet is touched, the leaflets nearest to the affected one first close in pairs and this is followed by the closure of adjacent leaflets in

pairs one after another. Evidently a stimulus passes down through the tissues of the leaf causing changes in the turgidity of the cells to result in the alteration of position. The leaf slowly resumes the former position after a few minutes, if it is kept undisturbed. The movement is brought about by variations in the turgidity of the cells on the opposite sides of the pulvinus. But recently it is believed that a hormone moves rapidly downward and produces the changes.

ANNEXURE

ANATOMY – FIGURES

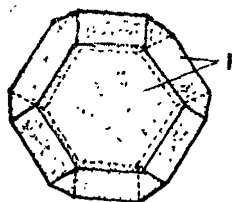


Fig. 2.16
Three dimensional model of a parenchyma cell—Orthic tetrakaidecahedron (diagrammatic)
1. facets

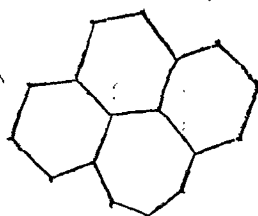


Fig. 2.17
Transection of parenchyma without intercellular spaces X 134

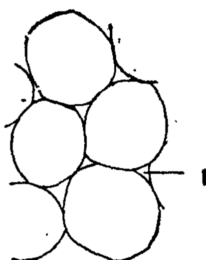


Fig. 2.18
Transection of parenchyma cell with intercellular spaces X 134
1. intercellular space

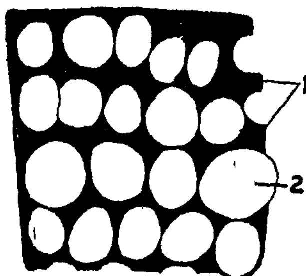


Fig. 2.19
Transection of angular collenchyma X 300
1. thickenings at the corners
2. collenchyma cell



Fig. 2.20
Xylem parenchyma strand (diagrammatic)
1. simple pits

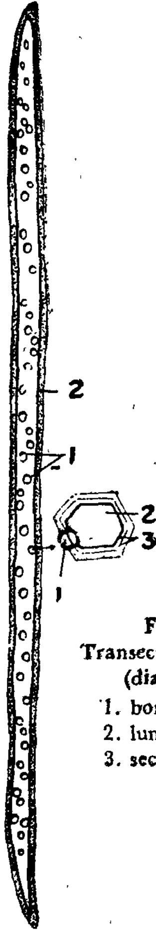


Fig. 2.22
Transection of a tracheid (diagrammatic)
1. bordered pit
2. lumen
3. secondary wall layers

Fig. 2.21
Tracheid (diagrammatic)
1. bordered pits
2. secondary wall

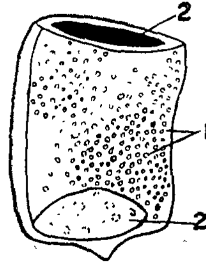


Fig. 2.23
Simple porous vessel member X 67
1. lateral wall pitting
2. end wall perforation

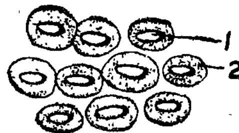


Fig. 2.24
Lateral wall pitting enlarged X 340
1. pit aperture 2. border

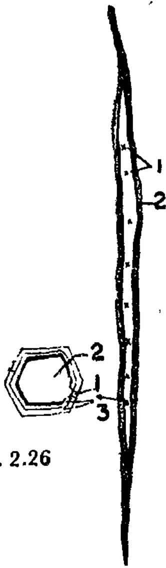


Fig. 2.26

Fig. 2.25
Fiber X 67
1. reduced bordered pits
2. secondary wall

Fig. 2.26
Transection of fiber (diagrammatic)
1. pit aperture 2. lumen
3. secondary wall layers



Fig. 2.27
Longitudinal section
of collenchyma X 340
1. thickening
at the corner

Fig. 2.28
Longitudinal section of a
root apex (diagrammatic)
1. calyptrogen 2. root cap
3. apical meristem 4. vascular region
5. cortex 6. epidermis
7. mucilagenous layer

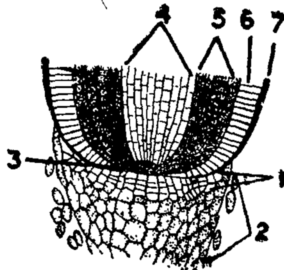


Fig. 2.28

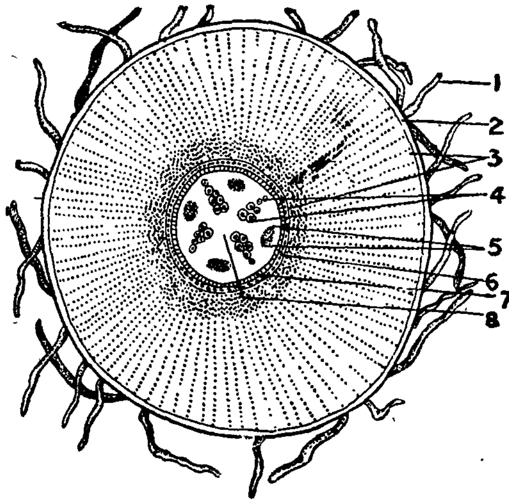


Fig. 2.29

Transection of young dicot root of *Ricinus communis* X 53
1. root hair 2. rhizodermis 3. cortex 4. primary xylem
5. primary phloem 6. endodermis 7. pericycle 8. pith

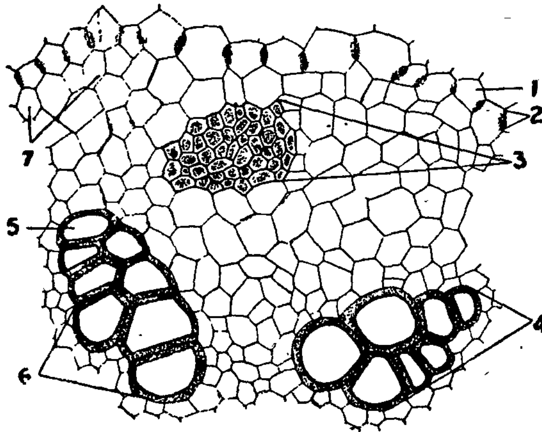


Fig. 2.30

Transection of a portion of young root of *Ricinus communis* (cortex omitted) X 90
1. endodermis 2. casparian thickening 3. primary phloem
4. primary xylem 5. protoxylem element 6. metaxylem elements
7. pericycle

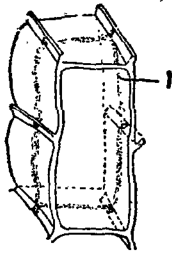


Fig. 2.31
Three dimensional model of an endodermal cell (diagrammatic)
1. casparian thickening band

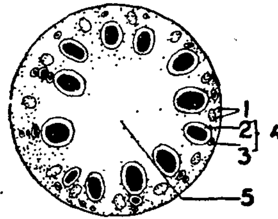
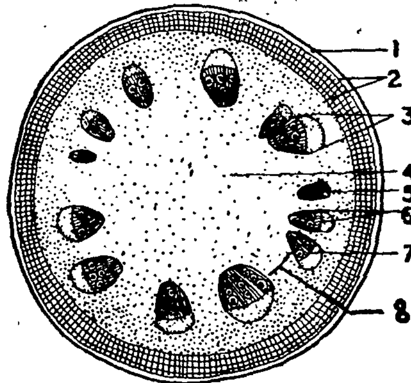


Fig. 2.32
Transection of stele of a monocot root (diagrammatic)
1. primary phloem 2. metaxylem element 3. protoxylem element 4. primary xylem 5. pith

Fig. 3.12 and 3.13
Ricinus communis

Fig. 3.12
Transection of young stem X 22
1. epidermis
2. cortex
3. vascular bundle
4. pith
5. fascicular cambium
6. primary xylem
7. primary phloem
8. medullary or pith ray



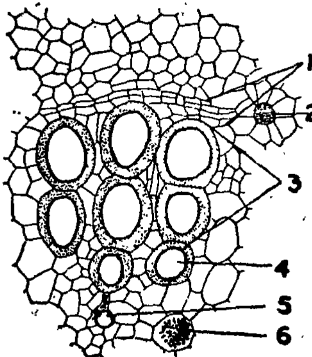


Fig. 3.13
Transection vascular bundle (cortex, epidermis omitted) X 134
1. fascicular cambium
2. secretory cell
3. metaxylem element
4. protoxylem element
5. protoxylem lacuna
6. druse

Fig 2.33 and 2.34
Chloris barbata

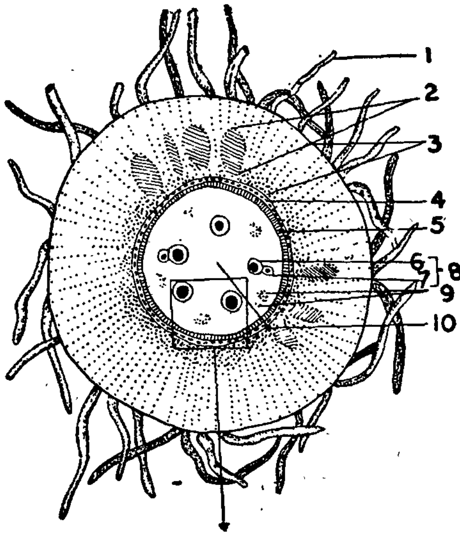


Fig. 2.33
Transection of root X 67

1. root hair
2. air-cavity
3. cortex
4. endodermis
5. pericycle
6. metaxylem element
7. protoxylem element
8. primary xylem
9. primary phloem
10. pith

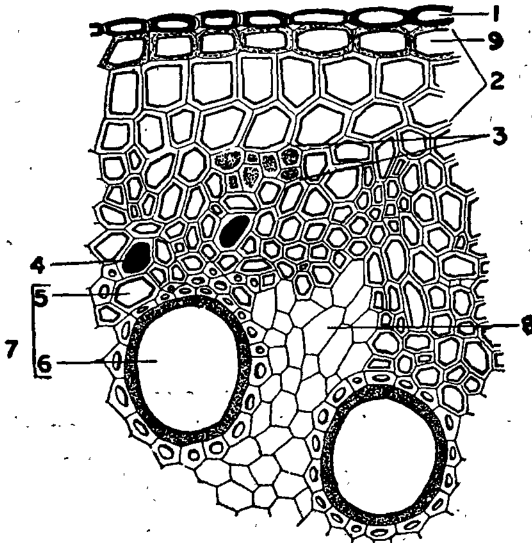


Fig. 2.34
Transection of a portion of root X 134

1. epidermis 2. cortex 3. primary phloem 4. tannin containing cell 5. protoxylem element 6. metaxylem element 7. primary xylem 8. ground tissue (parenchymatous) 9. pericycle



Fig. 3.14
Vessel (diagrammatic)
1. end wall perforation
2. vessel member (one lower end cut open to show the lumen)

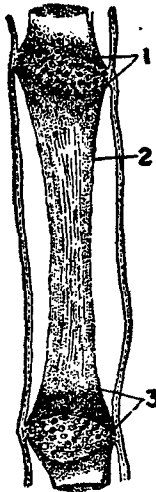


Fig. 3.15
Sieve tube element at the functioning stage X134
1. sieve plate (tilted)
2. slime
3. slime plug

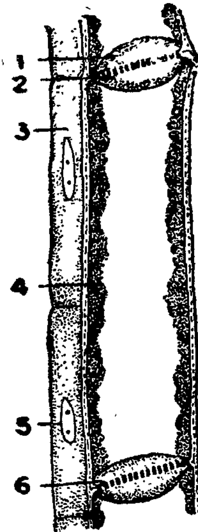


Fig. 3.16
Longitudinal section of sieve tube element at non functioning stage X134
1. callose
2. sieve plate
3. companion cell
4. cytoplasm
5. nucleus
6. sieve pore

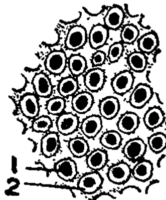


Fig. 3.17
Surface view of a portion of sieve plate (diagrammatic)
1 sieve pore 2. callose cylinder

Fig. 3.18 and 3.19 *Chloris barbata*

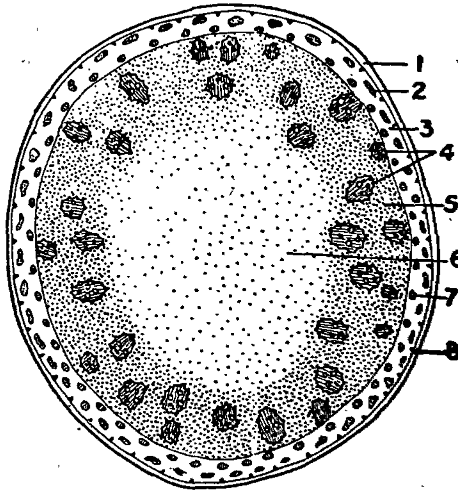


Fig. 3.18

Transection of culm—ground plan X 54

1. epidermis 2. chlorenchyma 3. cortex (sclerenchymatous) 4. vascular bundle 5. sclerenchymatous ground tissue 6. parenchymatous ground tissue 7. small vascular bundle 8. sclerenchyma strand

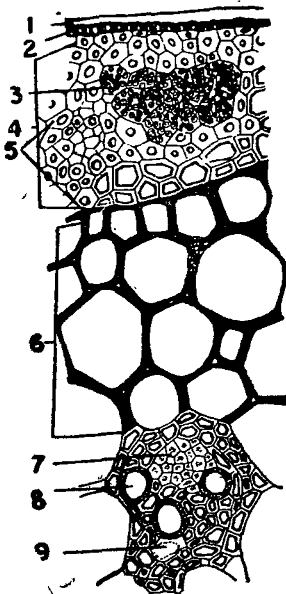


Fig. 3.19

Transection of part of culm as shown in Fig. 3.20 X 134

1. cuticle
2. epidermis
3. chlorenchyma
4. sclerenchymatous cortex
5. small vascular bundle
6. sclerenchymatous ground tissue
7. primary phloem
8. metaxylem element
9. protoxylem lacuna

Fig. 3.39 to 3.46 *Ricinus communis*

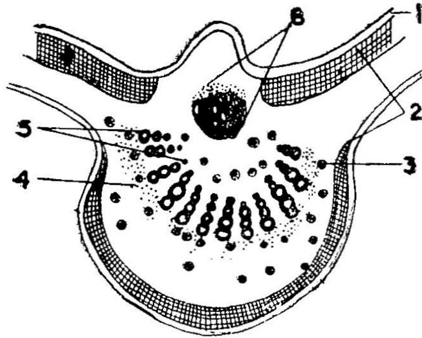


Fig. 3.37 Transection of midrib X 54

1. adaxial epidermis 2. hypodermal collenchyma 3. druse 4. primary phloem 5. primary xylem 6. adaxial vascular bundle



Fig. 3.38
Transverse section of stoma X 550

1. outer ledge
2. guard cell
3. subsidiary cell
4. substomatal chambet

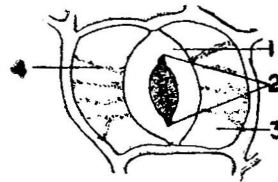


Fig. 3.39
Surface view of stoma X 550

1. guard cell
2. stomatal pore
3. subsidiary cell
4. cuticular thickening

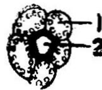


Fig. 3.40
Transection of veinlet X 550

1. border chlorenchyma 2. tracheid

X

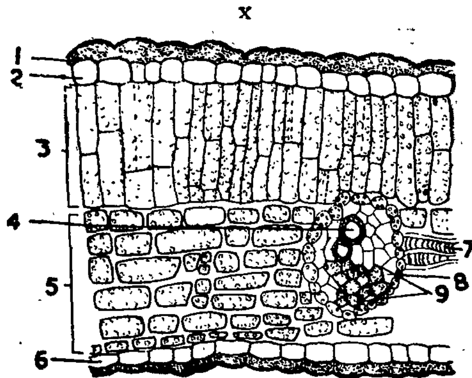


Fig. 3.41 Transection of lamina X 215
1. cuticle 2 & 6. adaxial and abaxial epidermis 3. palisade tissue 4. primary xylem 5. spongy mesophyll 7. longitudinal sectional view of a part of primary xylem element 8. border parenchyma 9. primary phloem

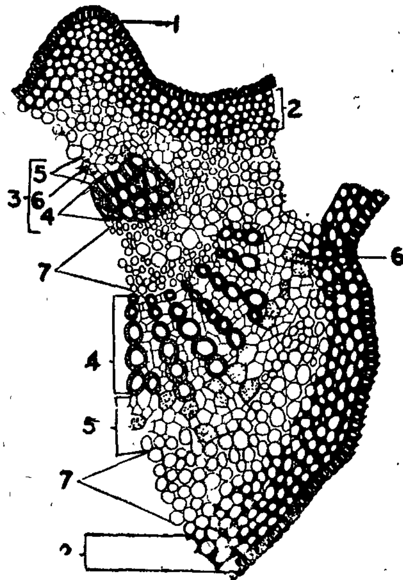


Fig. 3.42 Transection of midrib in part X 35
1. adaxial epidermis 2. hypodermal collenchyma 3. adaxial vascular bundle 4. primary xylem 5. primary phloem 6. sieve tube element 7. ground parenchyma

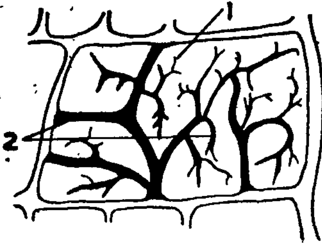


Fig. 3.43
Surface view of areole
(cleared lamina) X 75
1. veinlet 2. veins

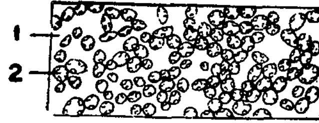


Fig. 3.44
Longitudinal section of
palisade tissue (diagrammatic)
1. intercellular space
2. palisade cells

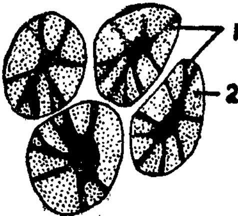


Fig. 8.7
Fruit of *Pyrus communis*—
Transection X 134
1. simple and ramiform pits
2. secondary wall layers

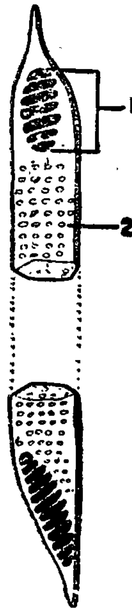


Fig. 8.8
Scalariform porous vessel
member (diagrammatic)
1. scalariform end wall
perforation plate
2. lateral wall pitting

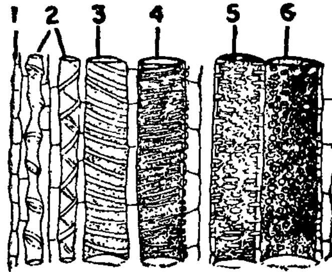


Fig. 8.9
Young internode of *Ricinus communis*—Longitudinal section (diagrammatic)
1. parenchyma 2. annular and stretched annular protoxylem elements 3. helical elements of protoxylem 4. scalariform elements of protoxylem 5. reticulate elements of metaxylem 7. pitted elements of metaxylem (all shown only in parts)

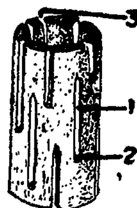


Fig. 8.10
Three dimensional block diagram of a vascular cylinder showing its dissection into leaf gaps and traces
1. leaf gap 2. vascular bundle
3. inter fascicular area



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